EUVL - A Reality in the Making

The Reality of Laser Assisted Discharge Plasma EUV Light Sources (S49)

2012 International Workshop on EUV and Soft X-ray Sources

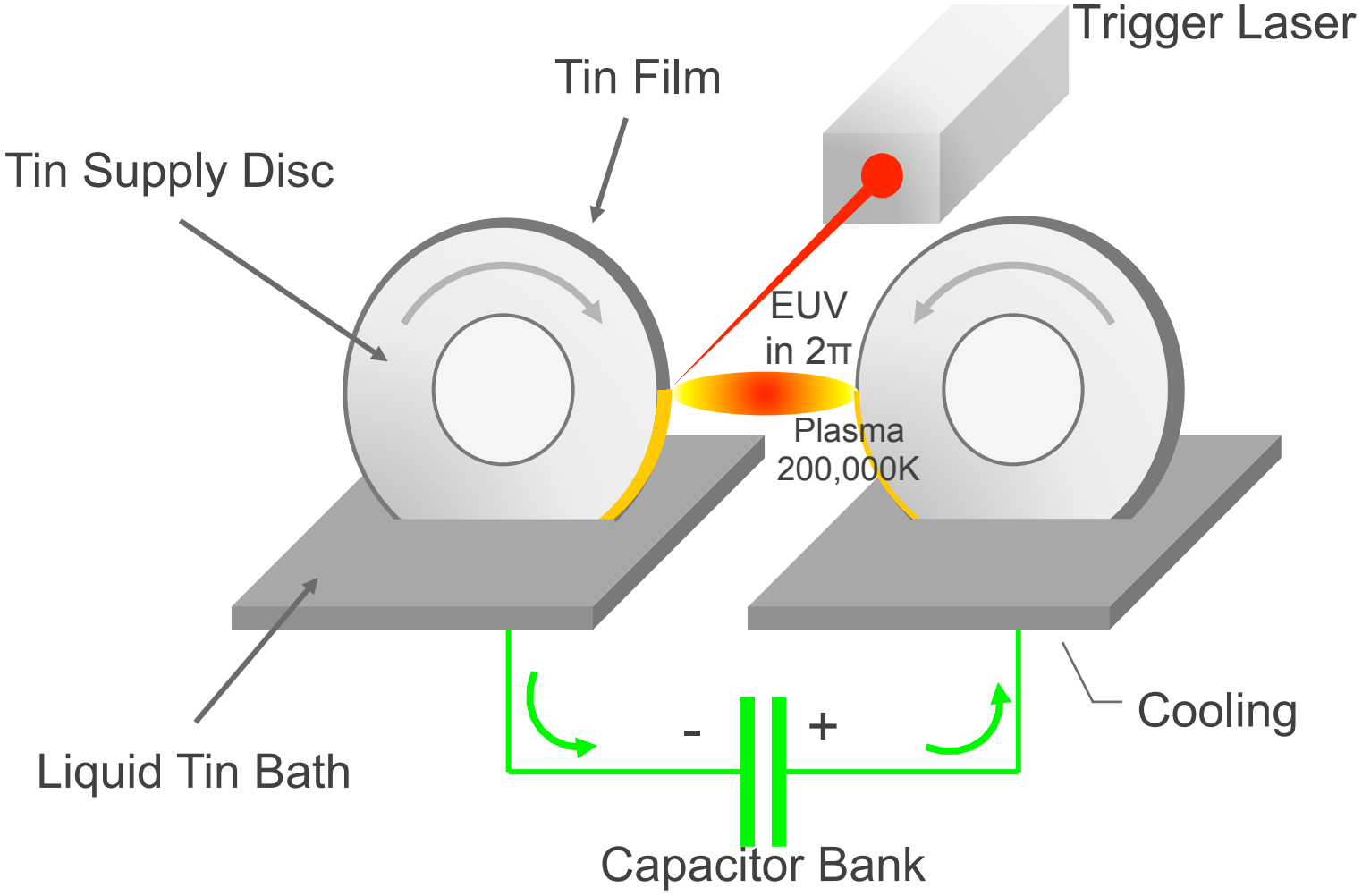
Dublin, October 2012

XTREME technologies

USHIO GROUP

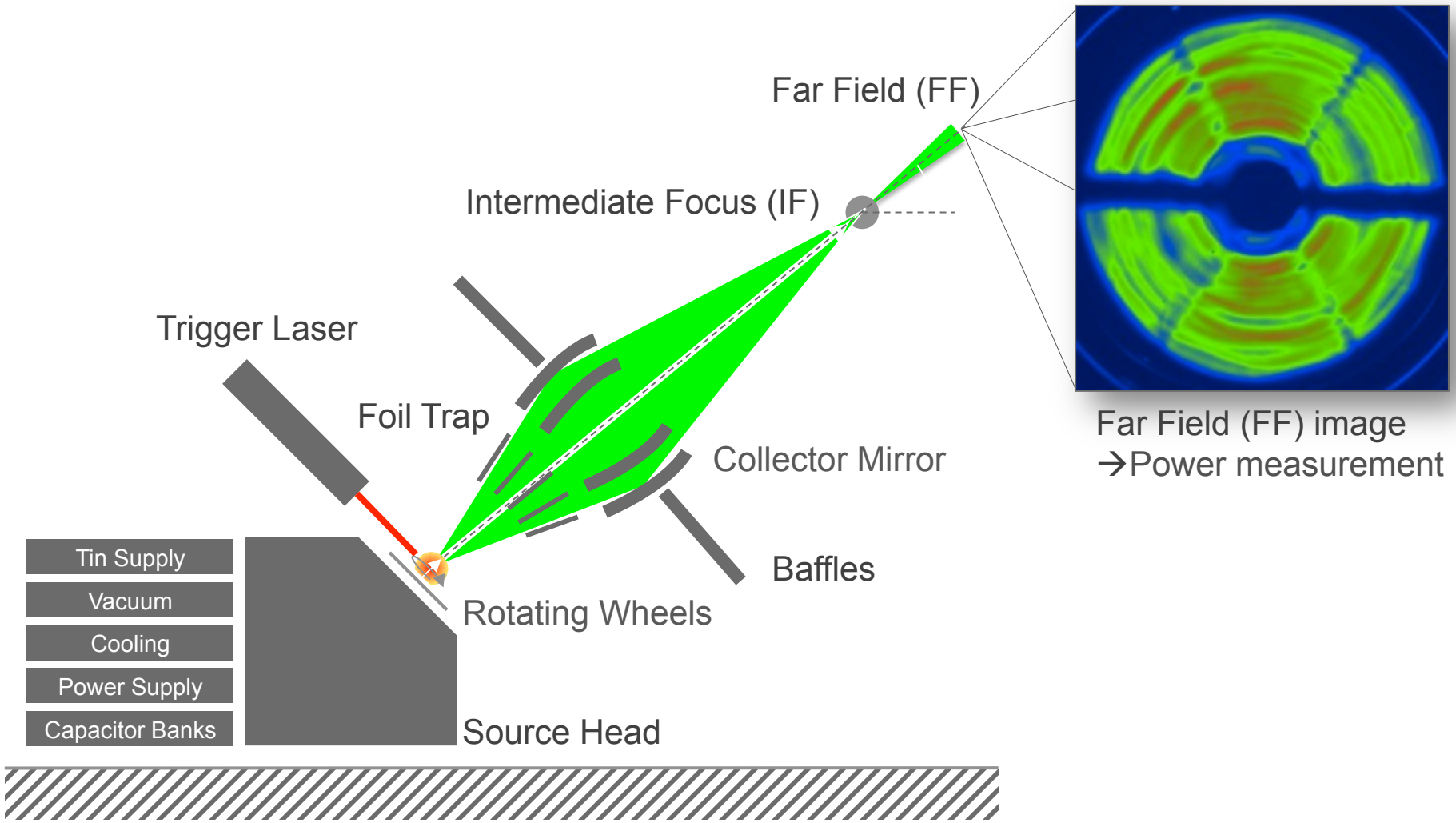
XTREME's LDP* Concepts – A Quick Refresher

***Laser assisted Discharge Plasma**

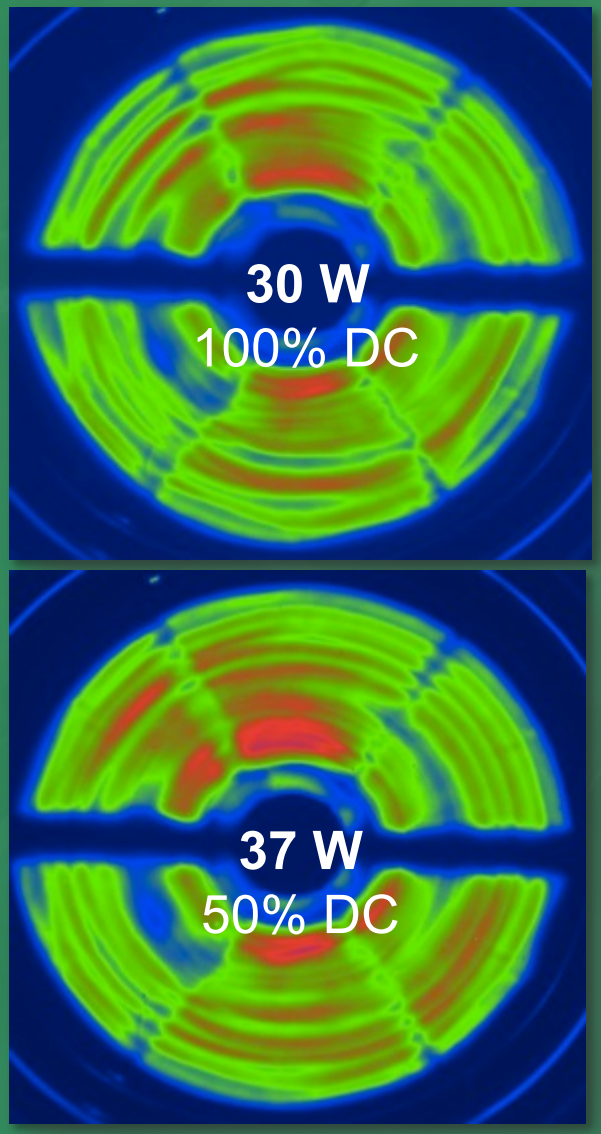


XTREME's LDP* Concepts – A Quick Refresher

***Laser assisted Discharge Plasma**



Where Were We Last Year ?



- Far Field images 35cm after IF
- Power refers to power after IF
- Power was actually measured after IF aperture
  - Not calculated from plasma power

The Biggest Headache ?

- **STILL … #1 Issue: Source**
  - **Power x Duty Cycle (= average power)** → **Throughput**
  - **Dose stability** → **CD uniformity → Yield**
  - **Availability / Uptime**

- #2 Issue: Mask
  - Defect density and contamination mitigation
  - Inspection tools and sources for inspection tools

- #3 Issue: Resist
  - Line edge roughness (LER)
  - Sensitivity
  - Resolution

Will EUVL Ever Be A Reality ?

- Will EUV light sources ever scale ?
- Could EUV light sources be turned into a product ?
- Do we have our priorities right ?
- Conclusions

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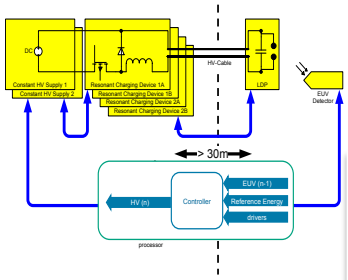
Could Physics Be Integrated Into A Viable Technology ?

- Last July, XTREME has resumed power scaling experiments on Ushio 3 integrated system to investigate short term scalability

Laser Engineering

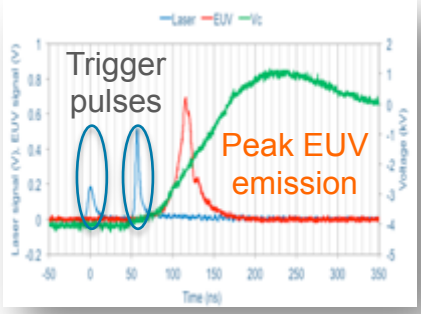
Tin Flow Engineering

Control Engineering

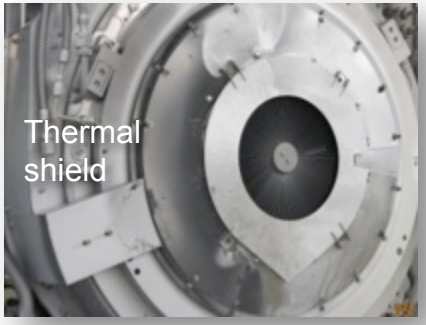


Real time dose control

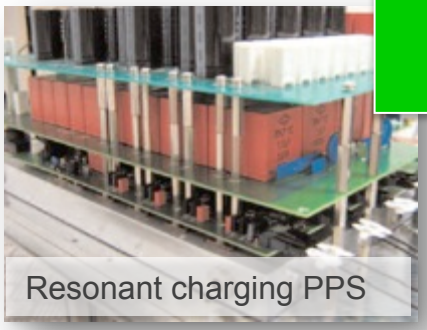
Plasma Engineering



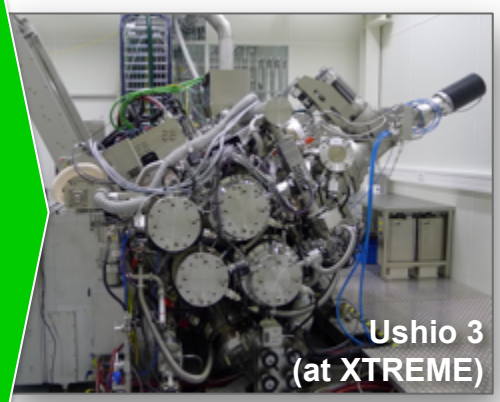
Thermal Engineering



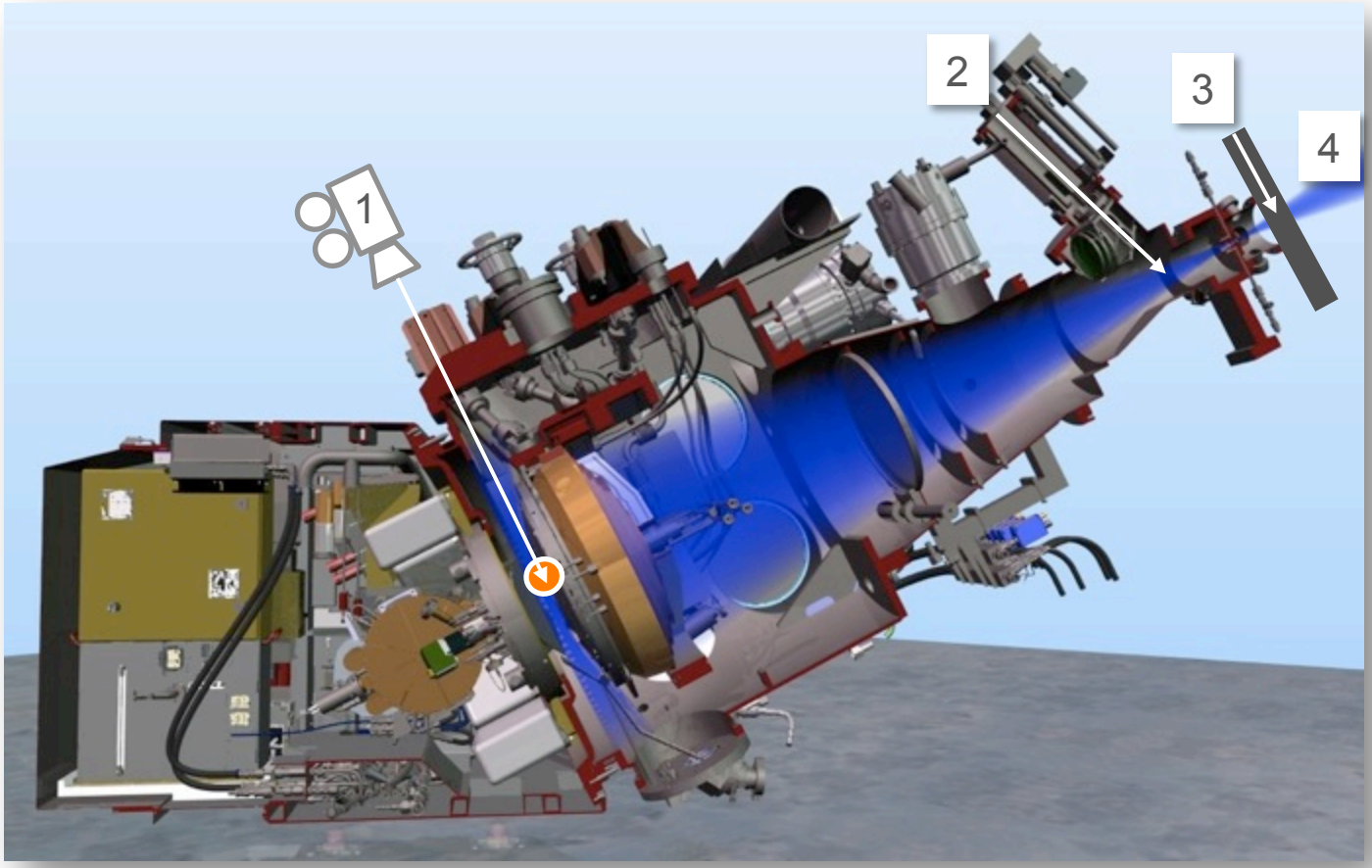
HVPS Engineering



Resonant charging PPS



Measuring Collectable EUV Power



1 - At plasma

collectable in-band power with pinch camera calibrated energy monitor

2 - Before IF

NFST camera can be moved in the EUV beam

3 - Behind IF

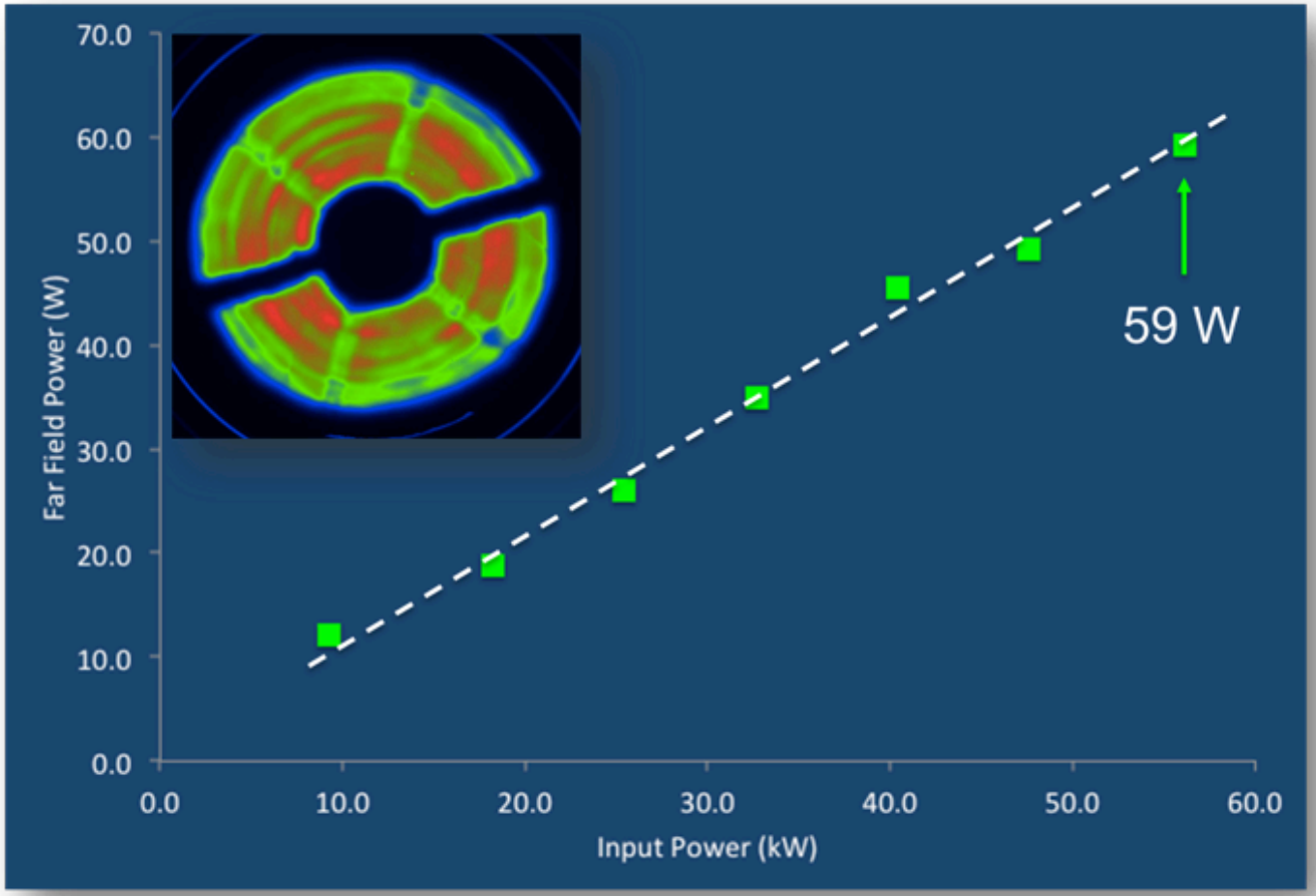
FFST (external sensor – XTREME only)

4 – Inside scanner

Energy Sensor at reticle level

Since Last Year …

- In July, 59 W after IF was achieved

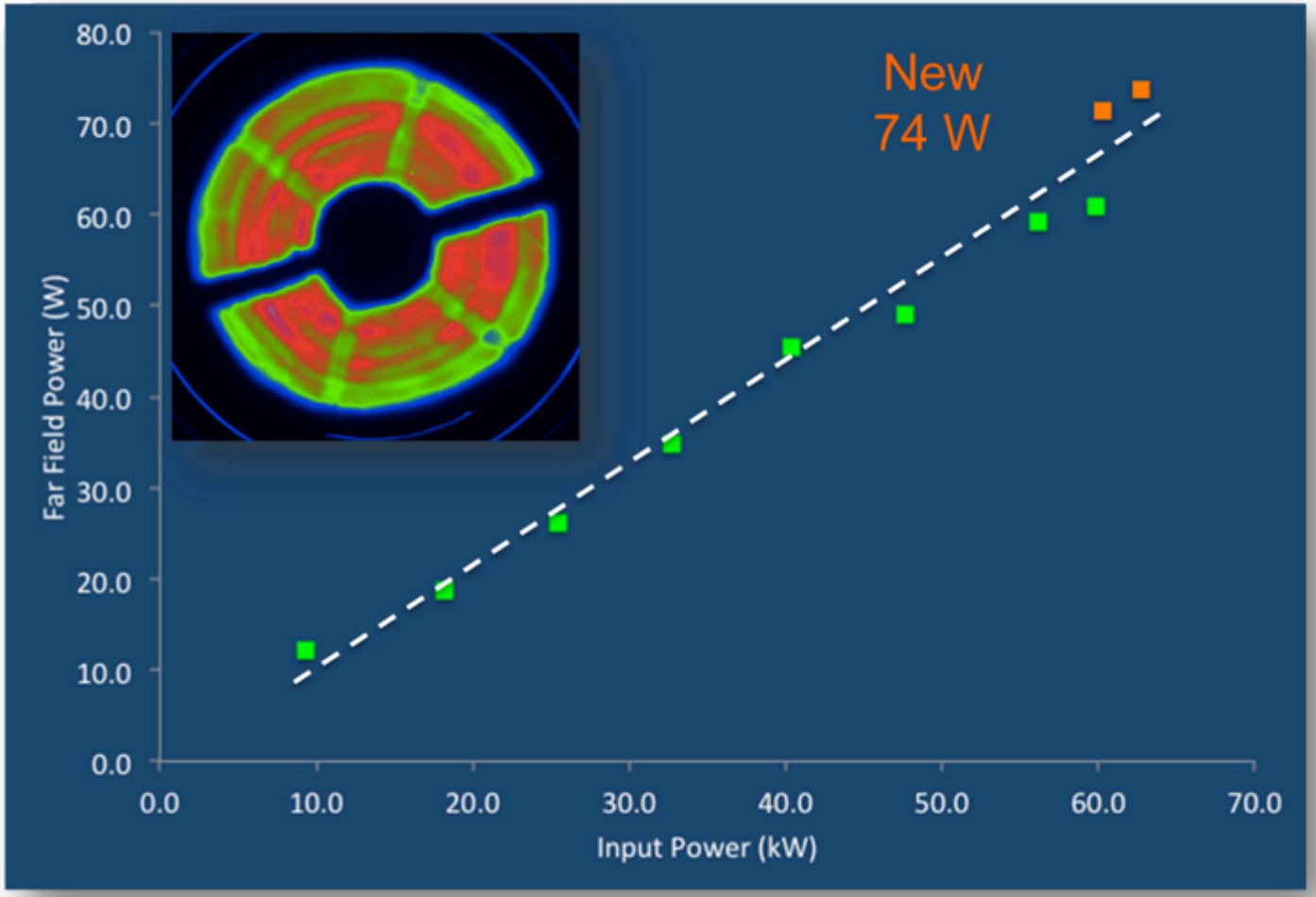


Excellent linearity was achieved

Burst mode
200 ms

Just In:

New Record 74 W After IF



Burst mode
200 ms / 12% DC

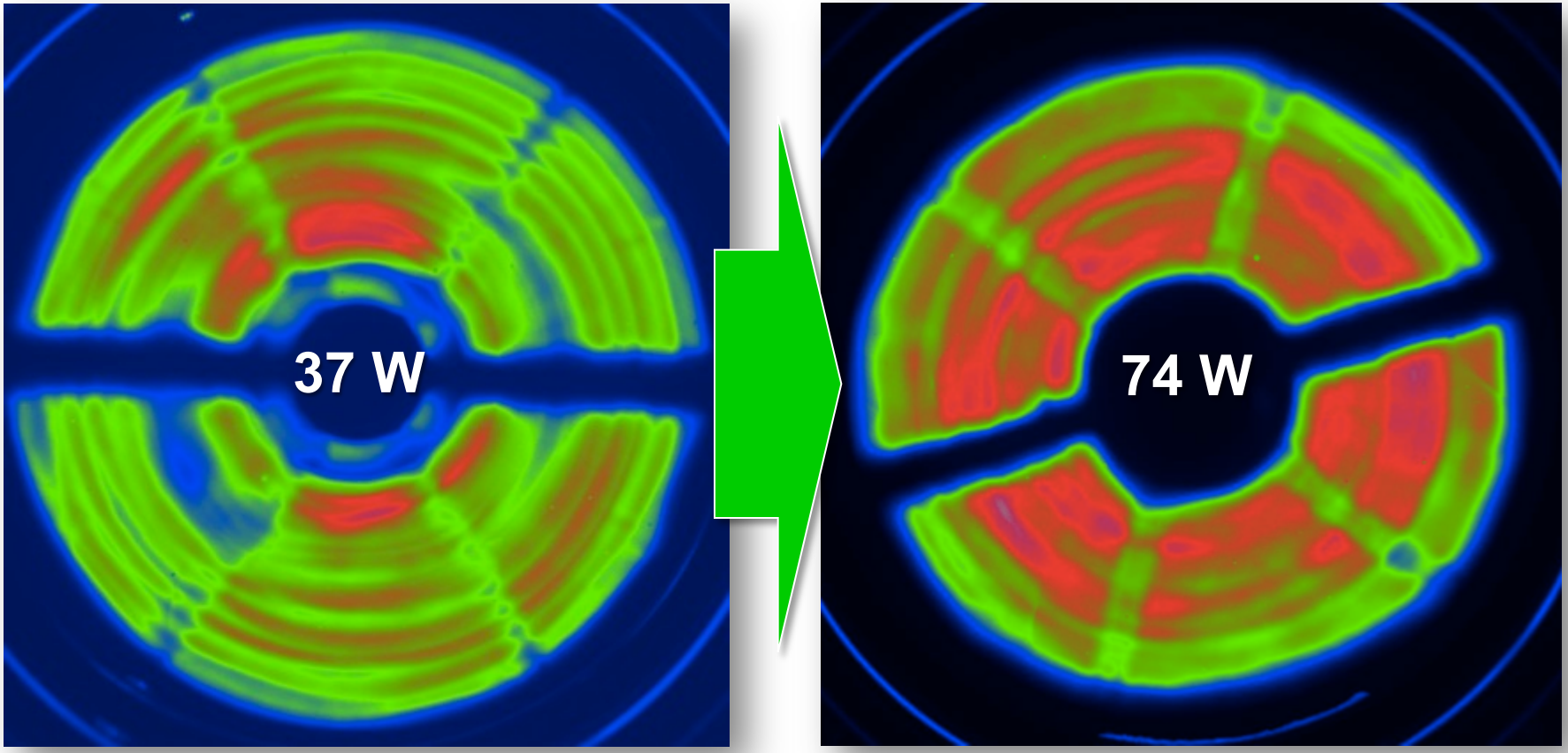
Pulse energy
3-4 J

1 hour run at 74W

LDP Has Made Steady Progresses

Last year

This year

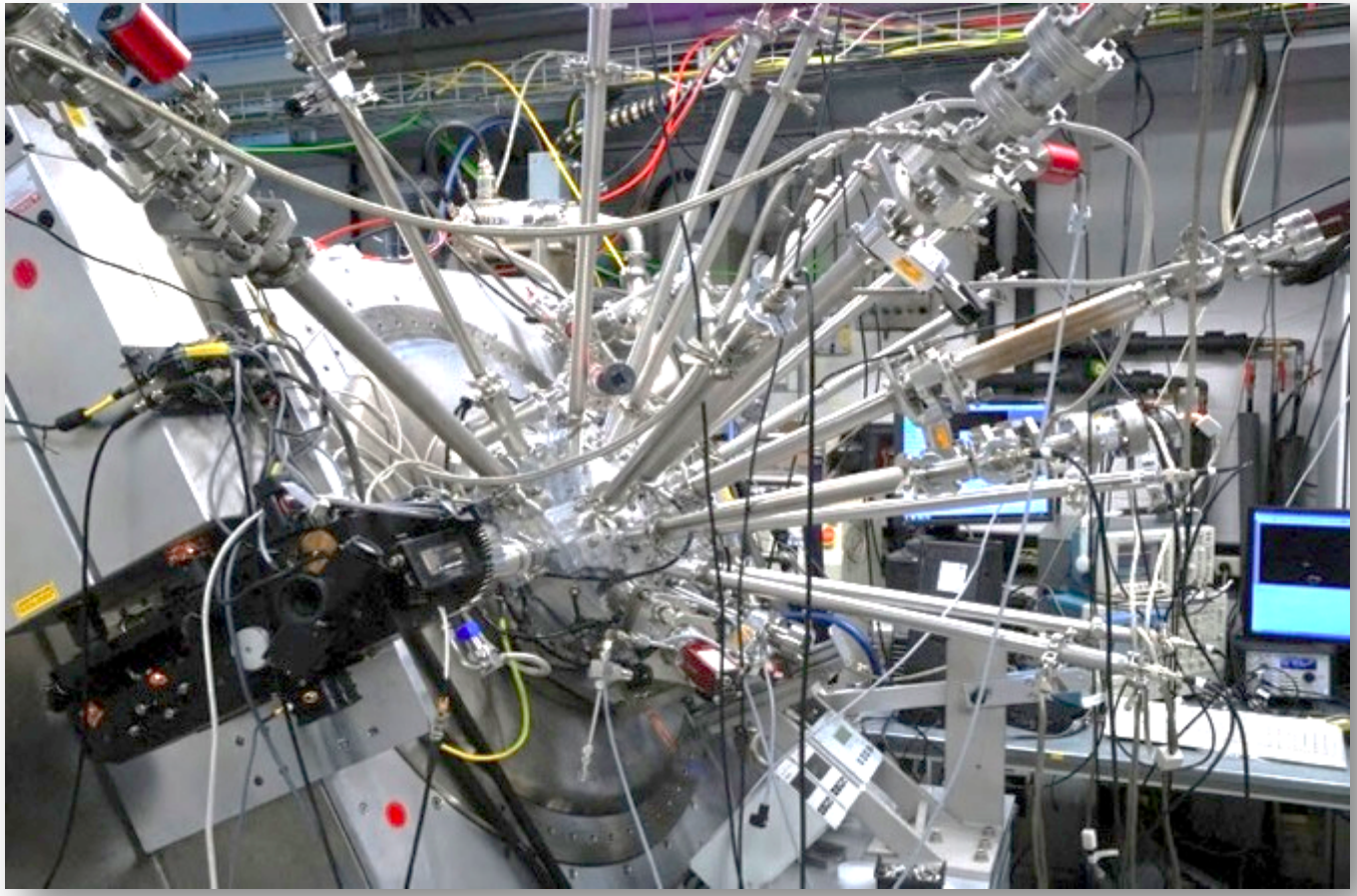


Integrated source Ushio 3
Burst mode

Could LDP Scale Beyond 250 W ?

- Why would anyone pursue a given technological path if it does not scale in the long term ?

  → A test stand (Obelix II) has been specially built to allow XTREME to validate LDP long term scalability



Power scalability:

- Reprate scalability
- Pulse energy scalability
- Conversion efficiency optimization
- Collection efficiency optimization

First, What It Means To Scale LDP

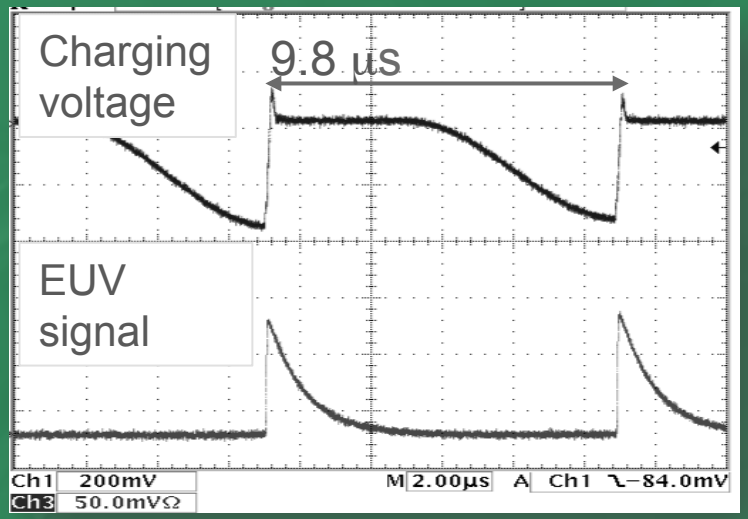
$$P_{IF} = \underbrace{f}_{P_{in}} \cdot E_{in} \cdot \underbrace{CE \cdot \eta_{col}}_{CCE} \cdot T_{opt}$$

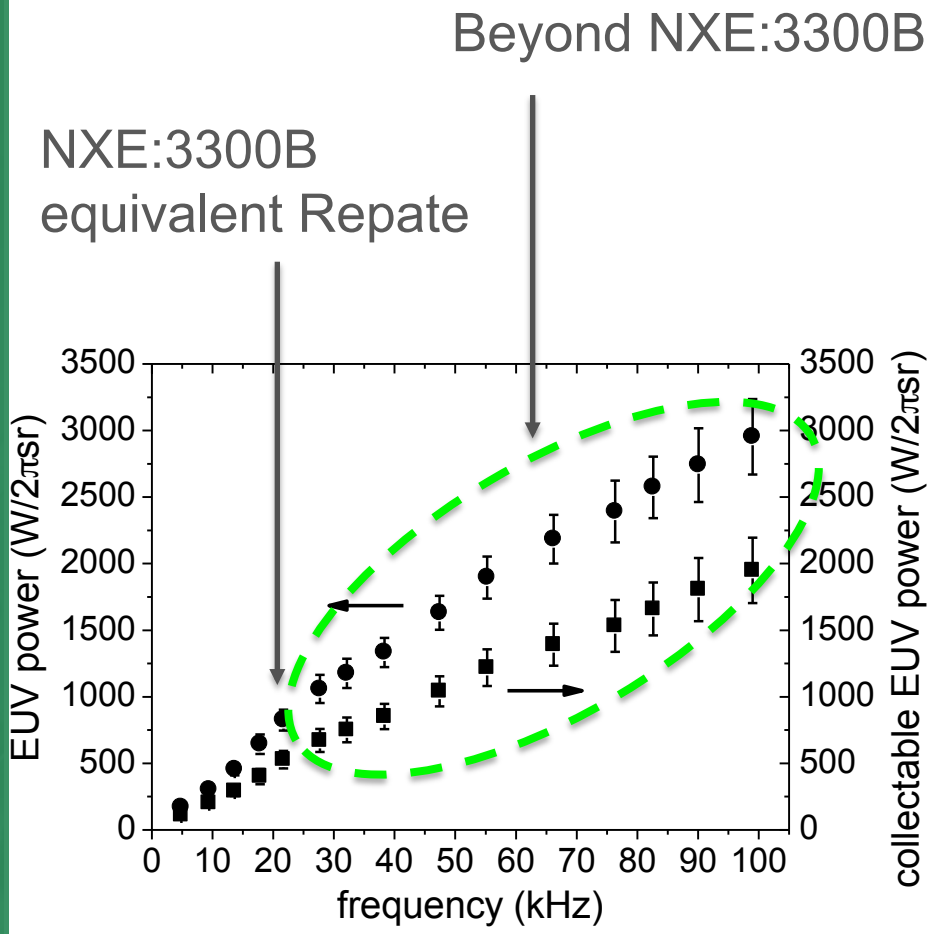
collectable EUV energy

P_{IF}	clean EUV power at IF
P_{in}	electrical input power
f	pulse repetition rate
E_{in}	energy stored in capacitor bank
CE	conversion efficiency
η_{col}	collection efficiency
T_{opt}	optical SoCoMo transmission
CCE	collectable conversion efficiency

LDP RepRate Scalability

- LDP's reprate long term scalability is proven **BEYOND the requirements for 3300B (250W)**
  - Interlaced low energy pulses experiments

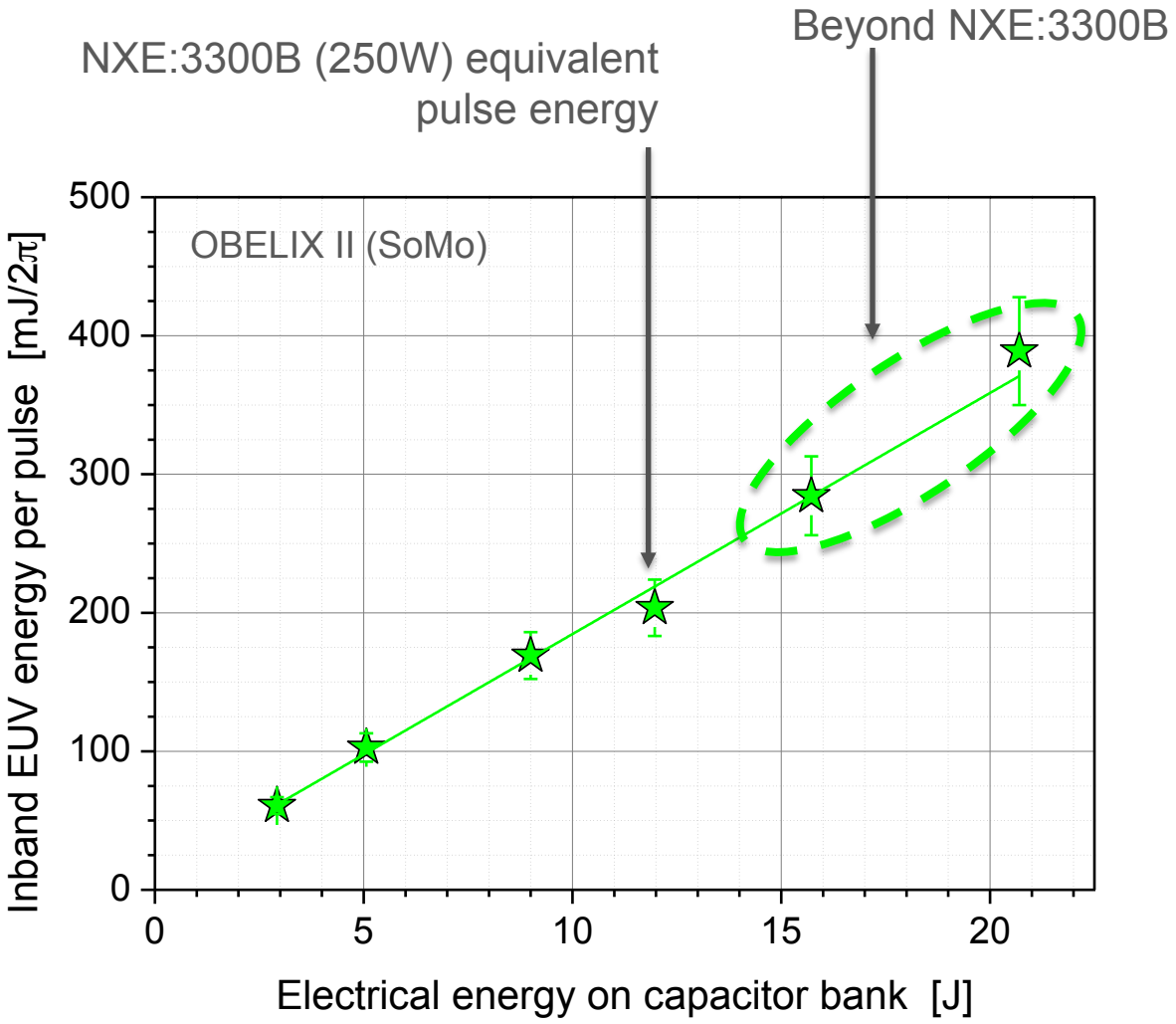




Experiment
Frequency = 1/(ΔT between pulse 1 and 2)

LDP Pulse Energy Scalability

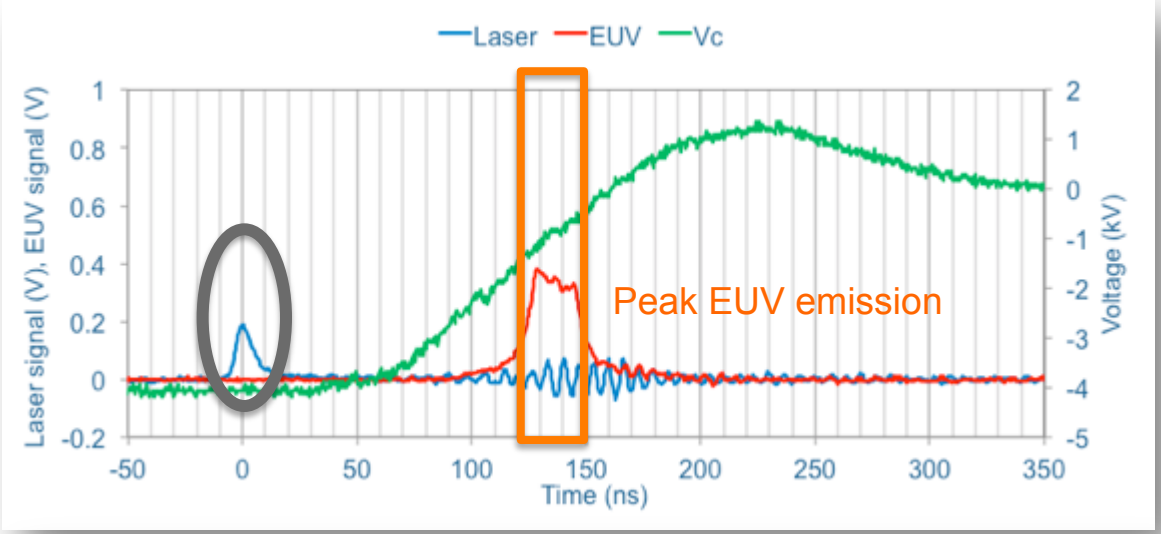
- LDP's long term pulse energy scalability is proven BEYOND the requirements for NXE:3300B (250W)



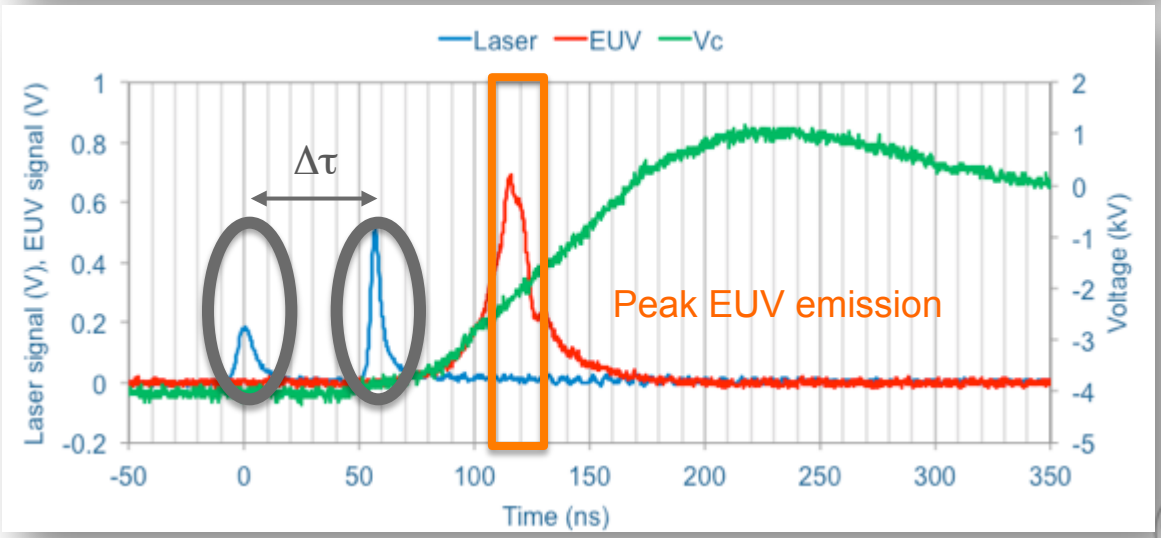
Plasma Engineering

- Tailoring the laser pulse train allows XTREME to engineer the plasma emission

Single trigger laser pulse

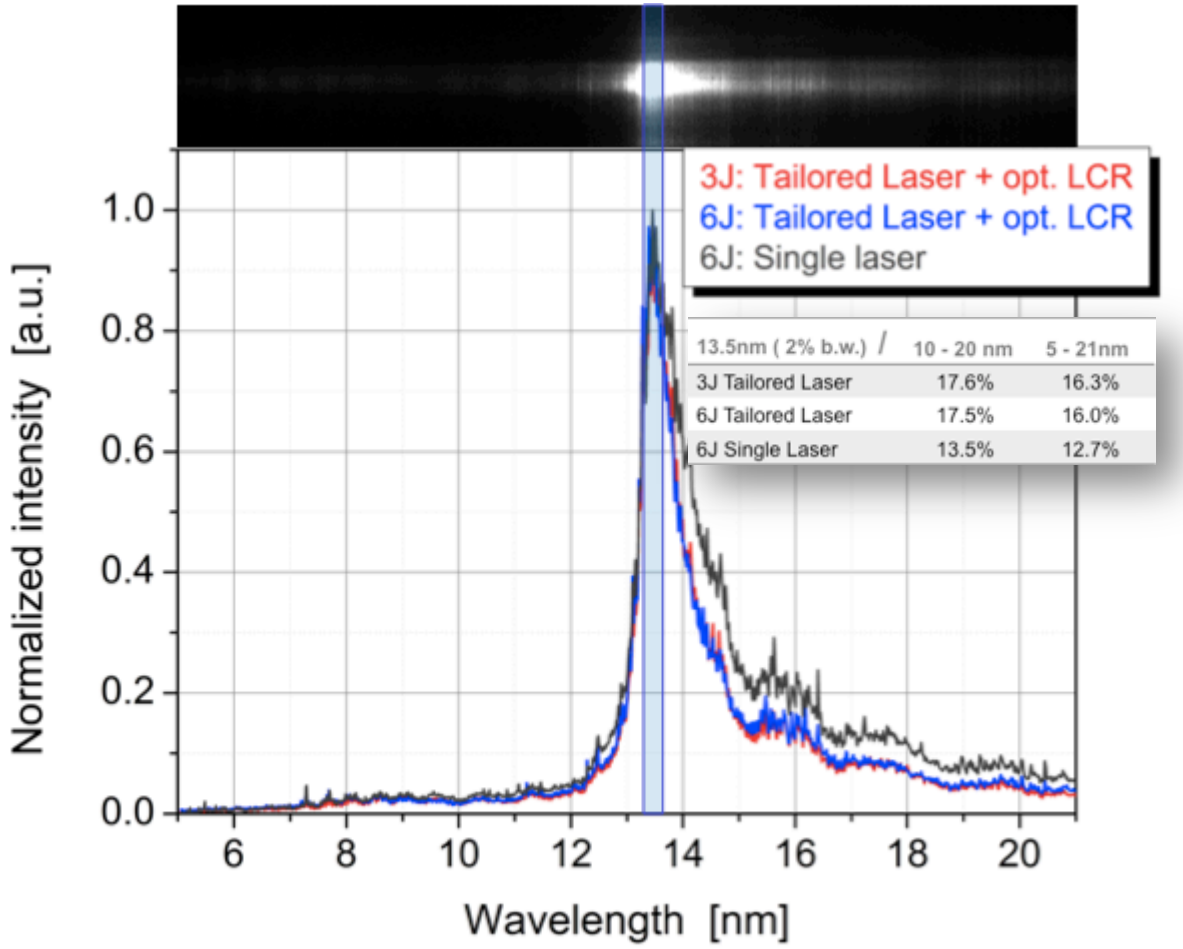


Double trigger laser pulse



Engineering The Emission Spectrum

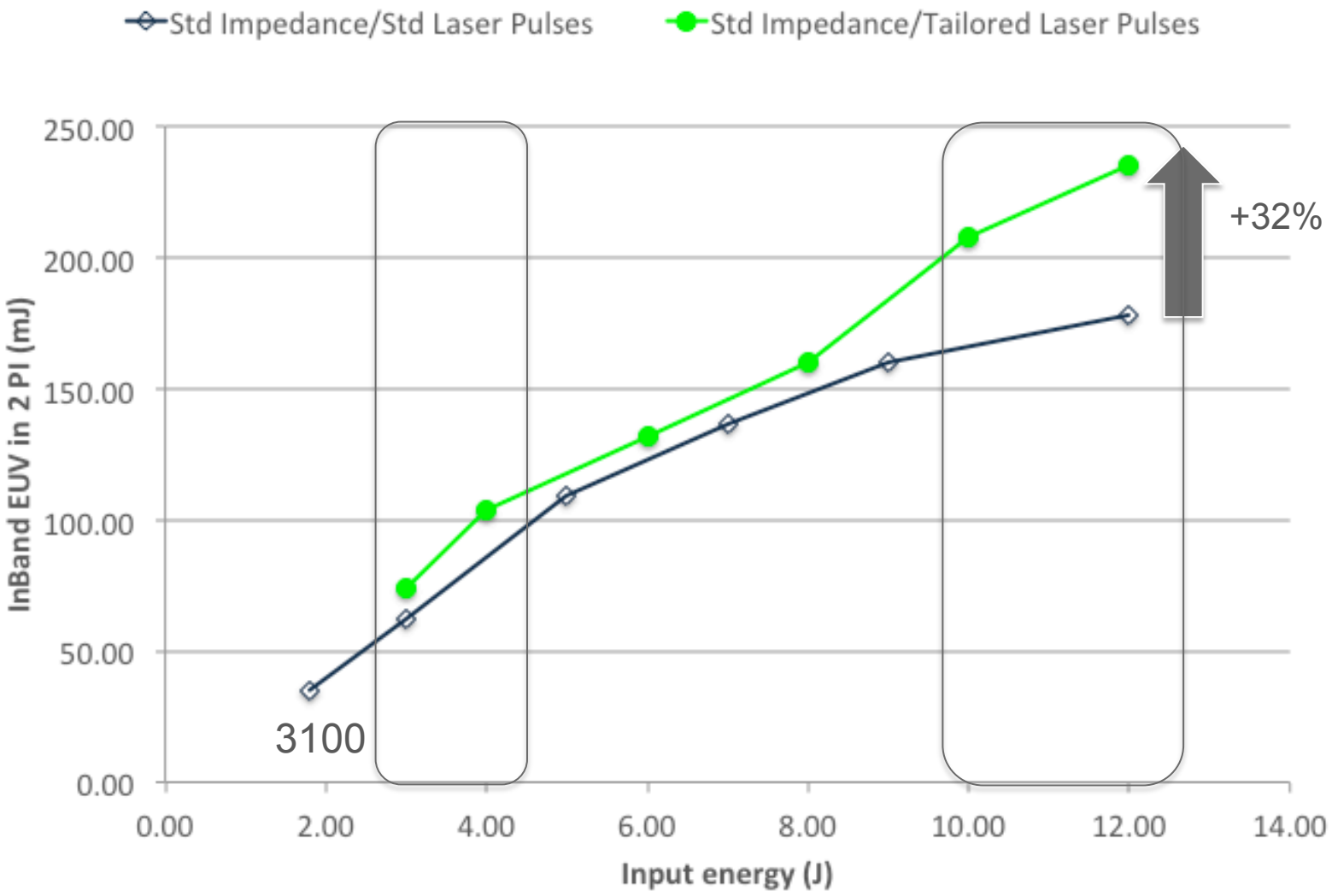
- Tailoring the laser pulse trains yield improvement in the emission spectrum (1.3X) and the out of band EUV content



Spectral purity was also proven not to change with increasing input electrical energy

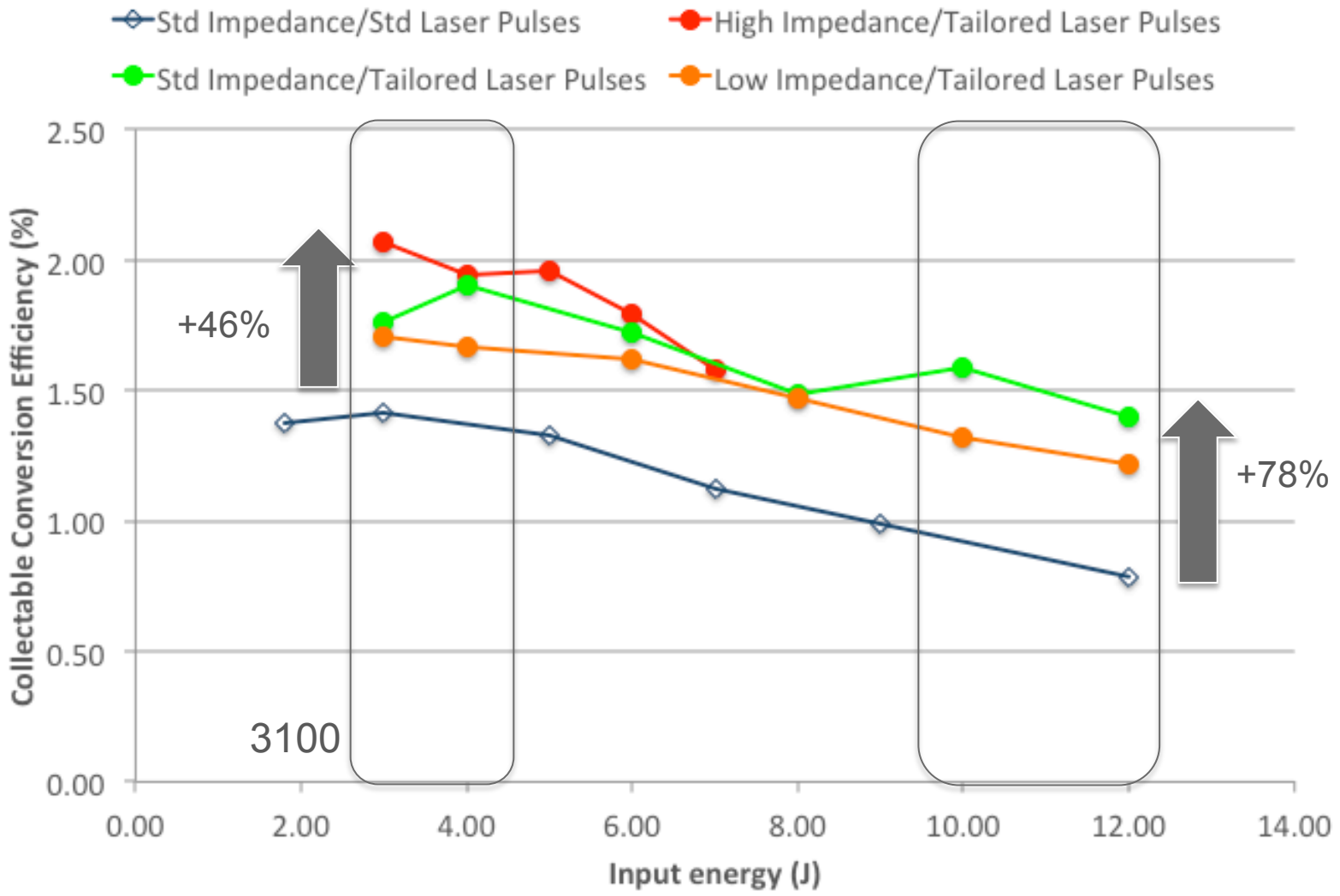
Can we further tweak the Sn spectrum to get more in band (2%) EUV ?

Engineering Pulse Energy With Lasers



Engineering Collectable Conversion Efficiency

- CCE (Collect. Conv. Eff.) = Conversion Efficiency x Collection Efficiency



Will EUVL Ever Be A Reality ?

- Will EUV light sources ever scale ?
- Could EUV light sources be turned into a product ?
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- Conclusions

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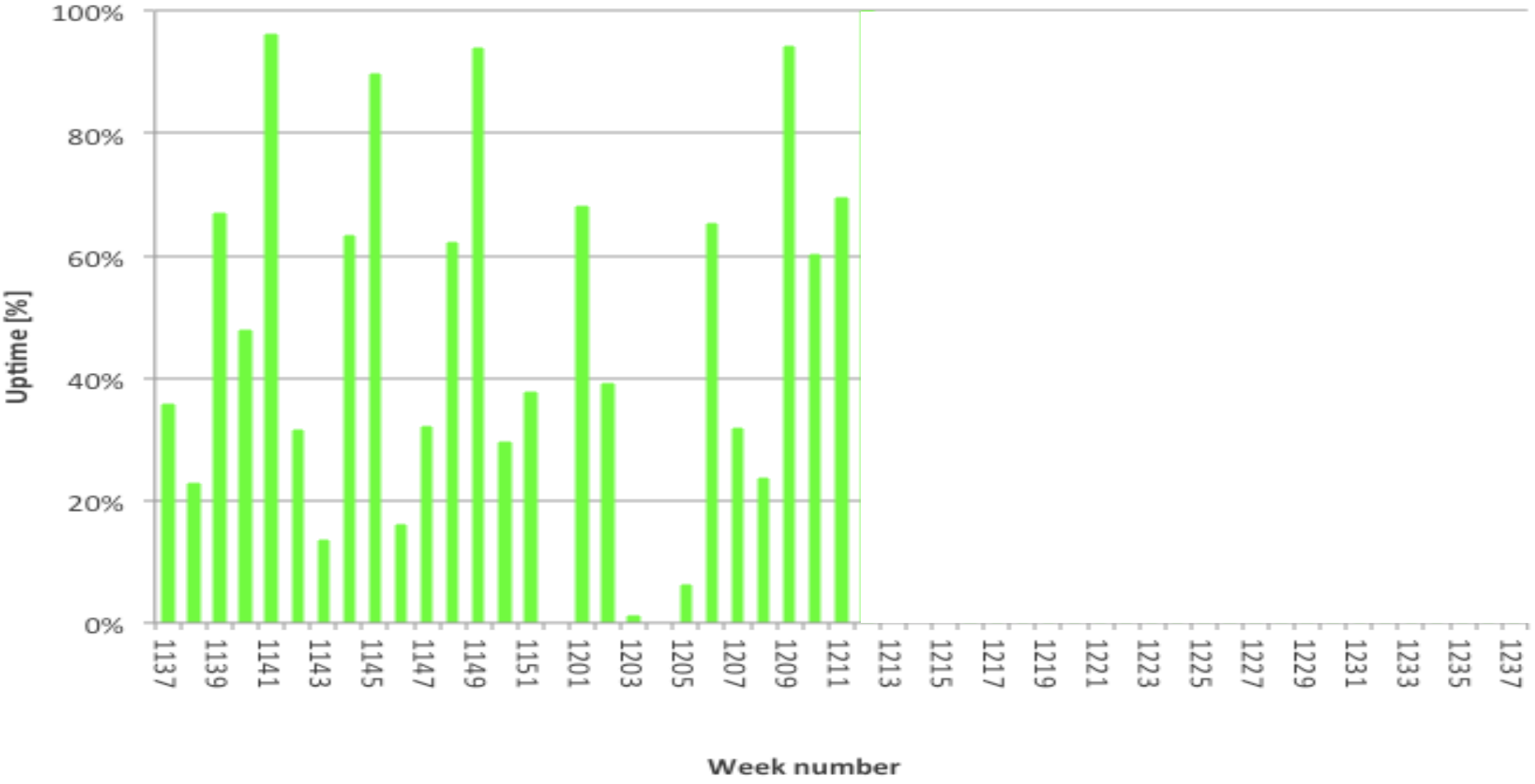
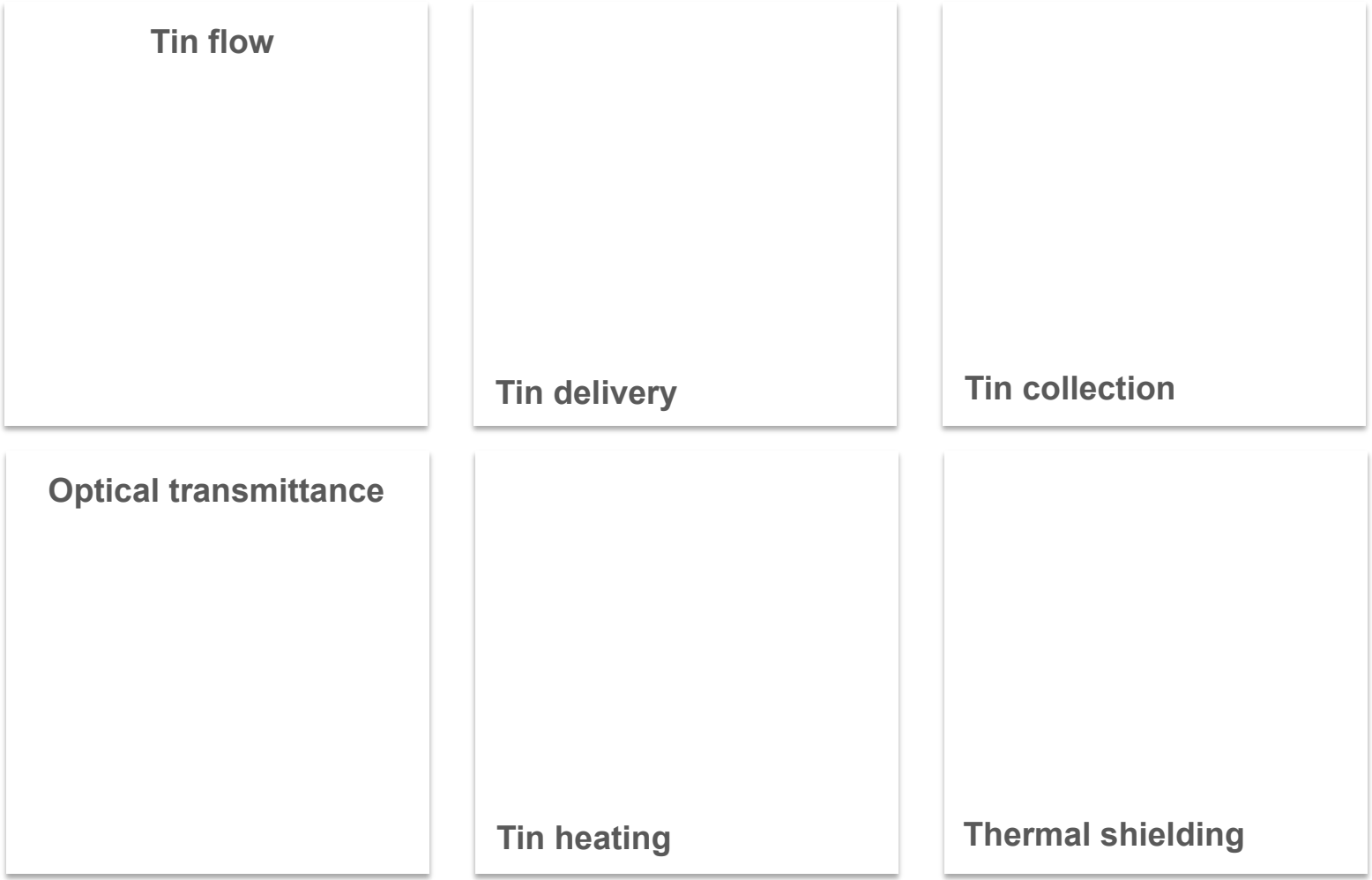
The Not So Long Ago Early Days Were Painful

- Ushio 1 source at IMEC initial availability was very disappointing



Turning Technology Into A Product

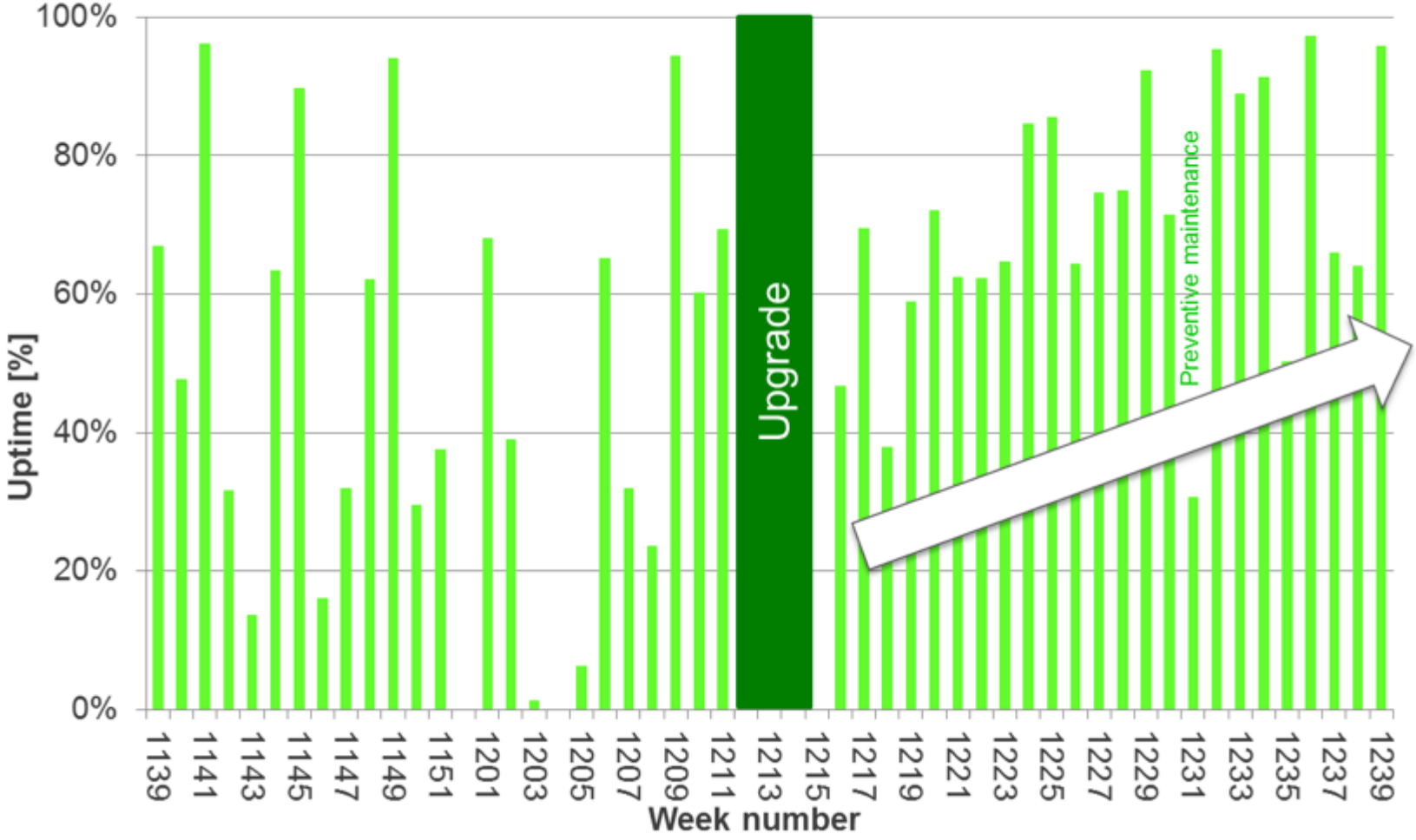
- To stabilize the technology, over H1 2012, XTREME reallocated resources, launched a major re-design effort and upgraded Ushio 1



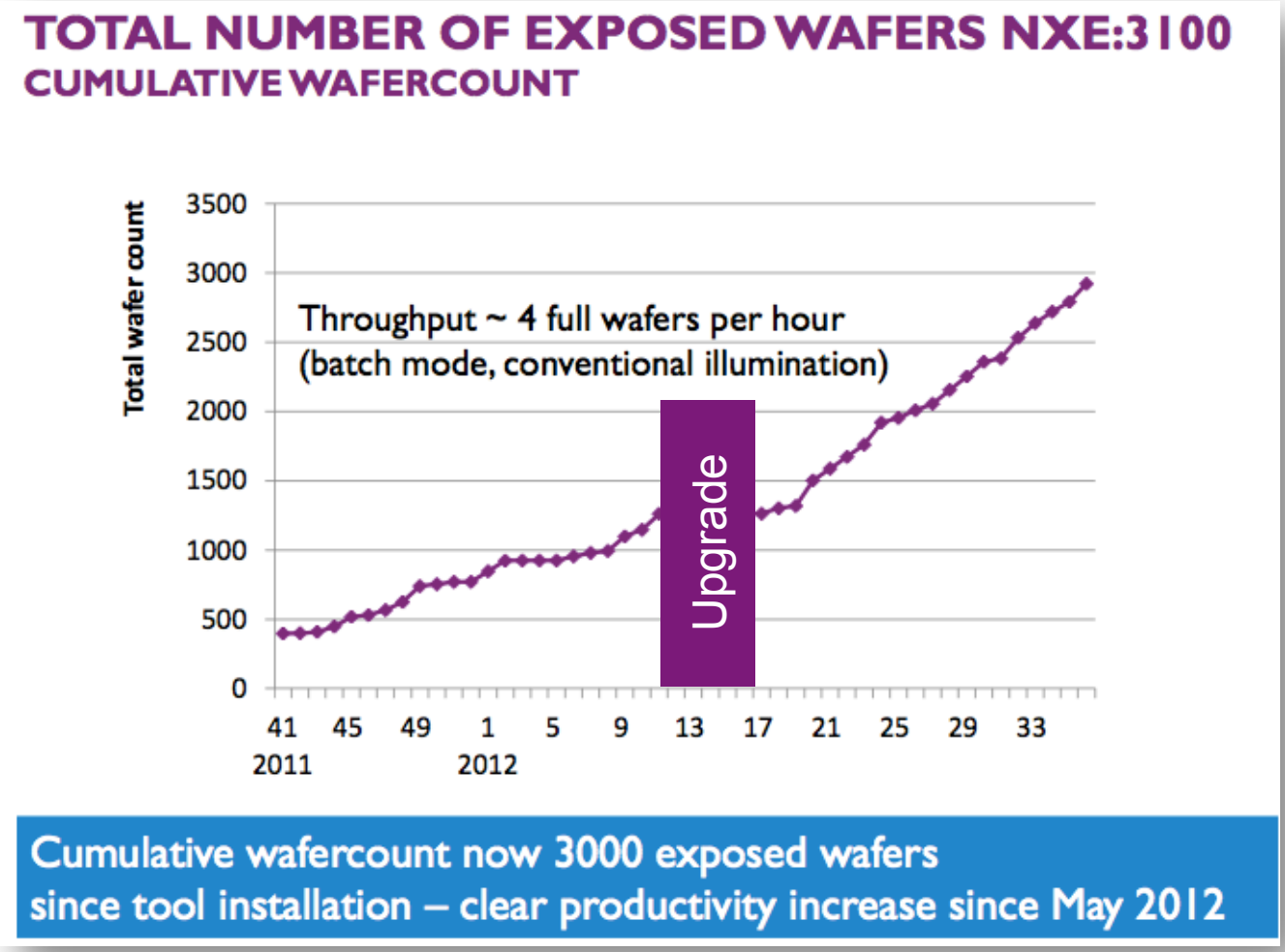
Pictures not for hand out

After Upgrade, Ushio 1 Uptime Has Steadily Increased …

- Recently, uptime exceeds 90% (13 wk average now exceeds 75%)
- Volatility has also drastically decreased



… And Utilization (7x24) Is High

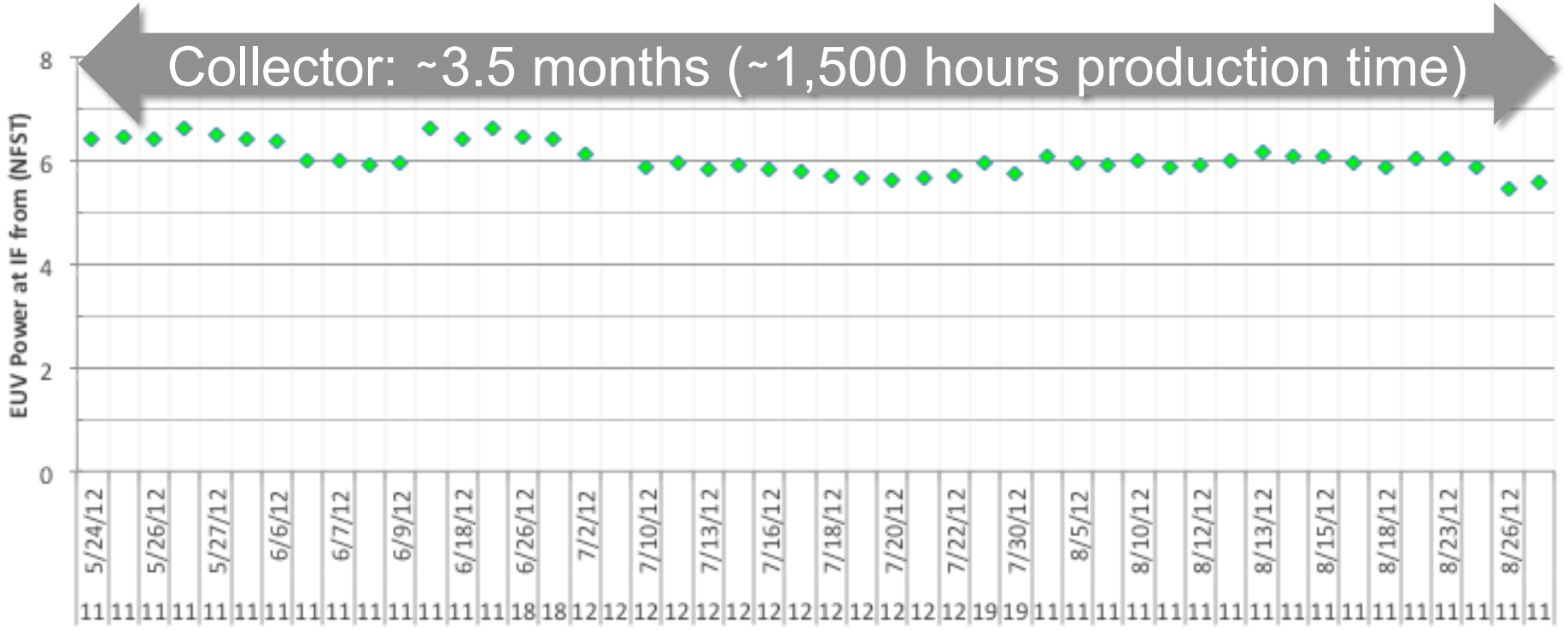


3,000 wafers have been printed so far

Courtesy imec

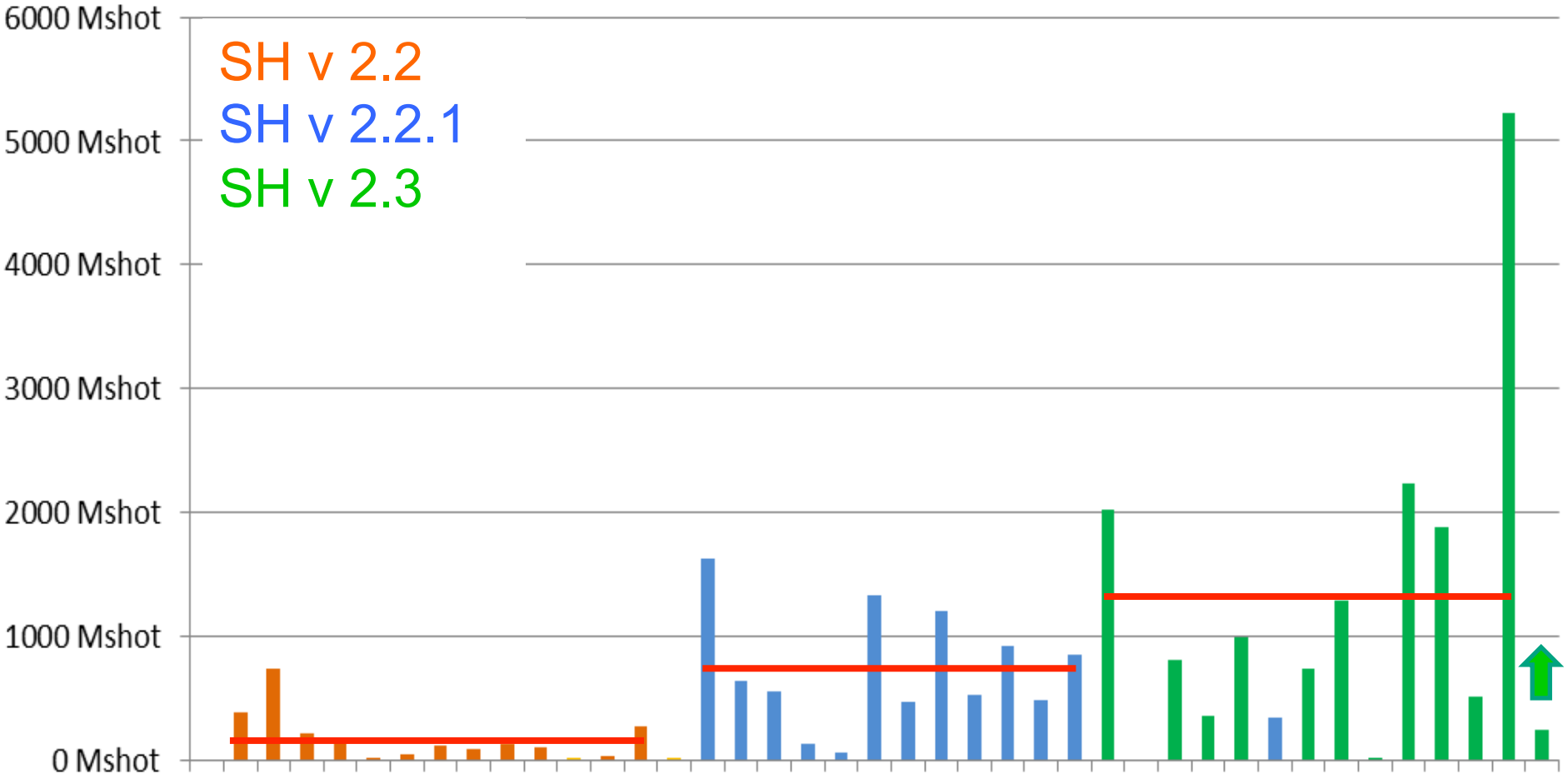
Long Collector Lifetime Is Achieved

- Power at IF is stable over the collector life



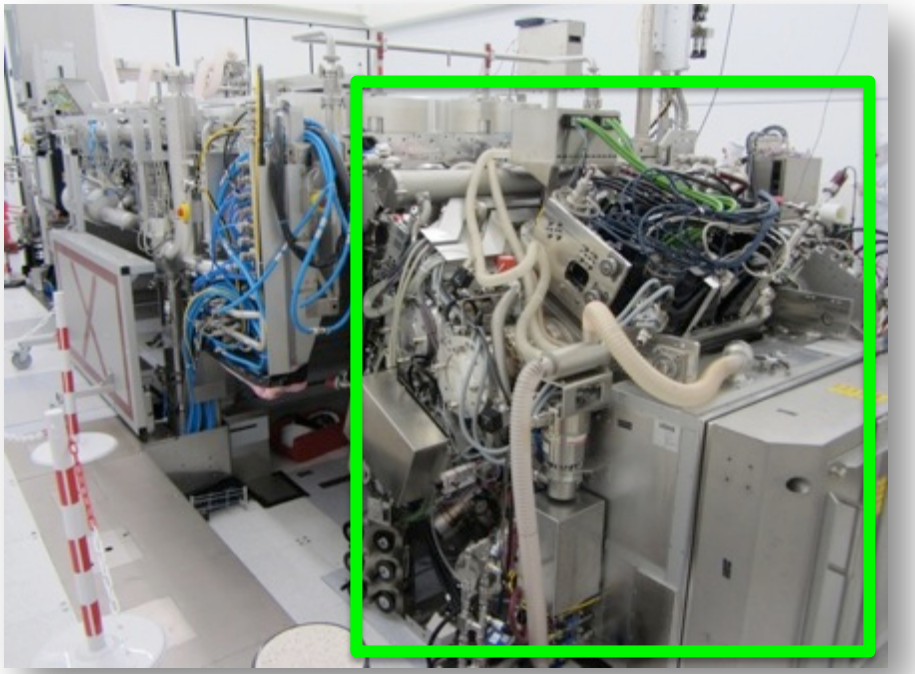
Lifetimes Have Increased

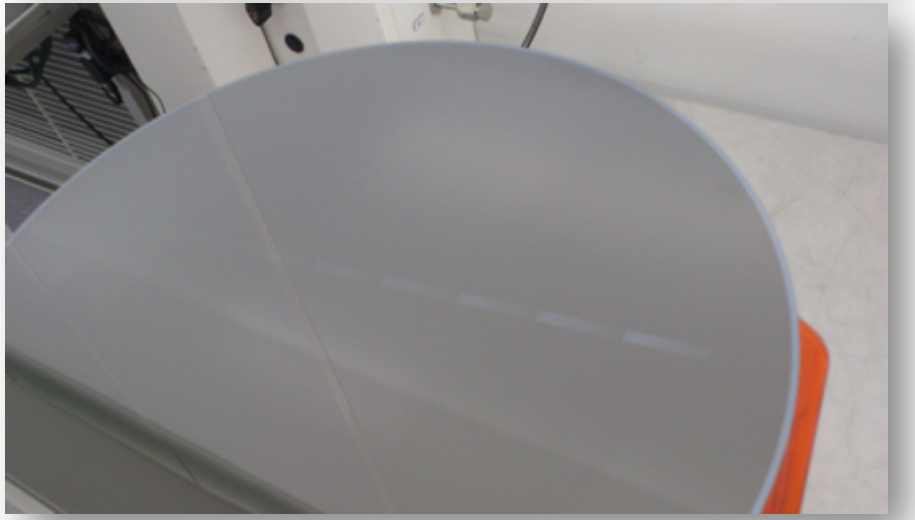
- Source Heads (SH) are no more the primary source of downtime



U2 & U4 @ ASML

- Ushio 2 & Ushio 4 light sources (3100) are integrated to NXE: 3300B to support scanner development
- U2 (20 kW configuration) & U4 (50 kW configuration) are being upgraded as well
- U2 has now printed its first wafer





Courtesy ASML

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Power, Power, Power !!! … Simply More Power ?

POWER → THROUGHPUT

&

DOSE STABILITY → YIELD

Can we really talk about power without talking about dose stability

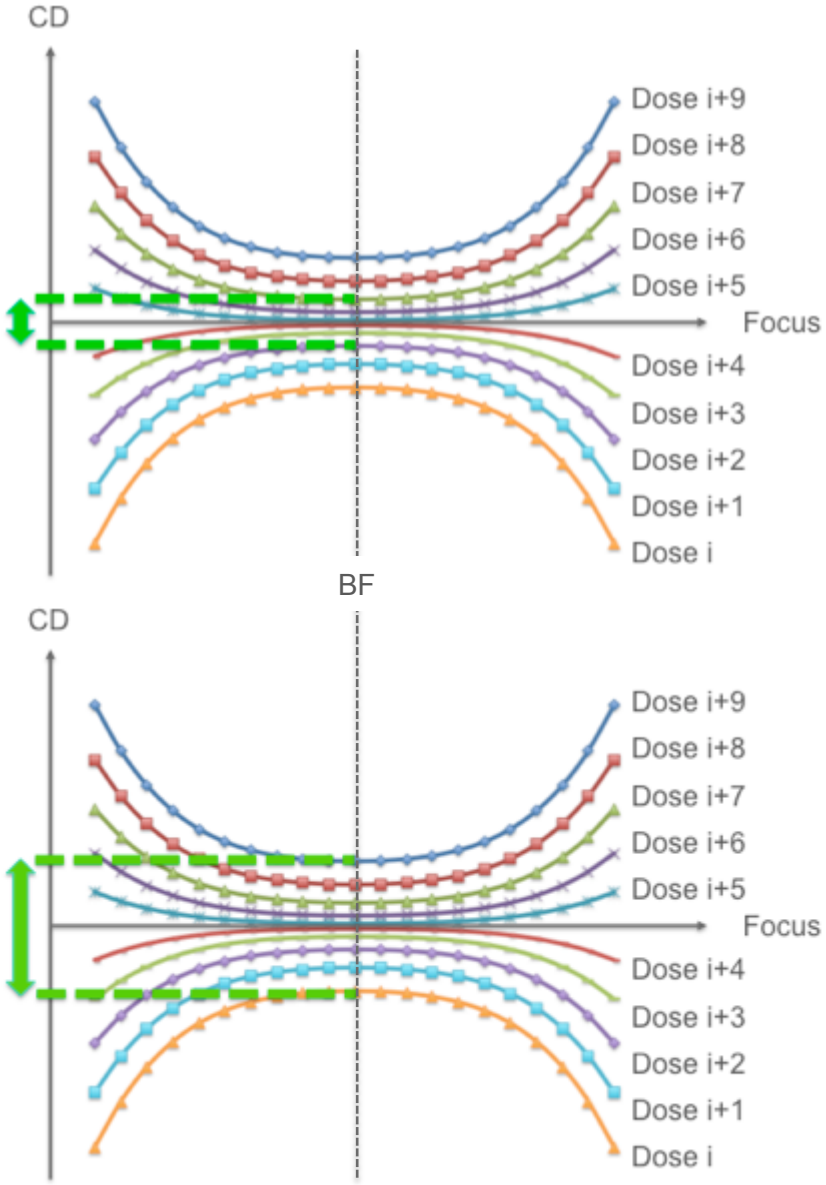
?!?!?

Why Does Dose Stability Matter ?

ASML dose specifications for EUV sources:

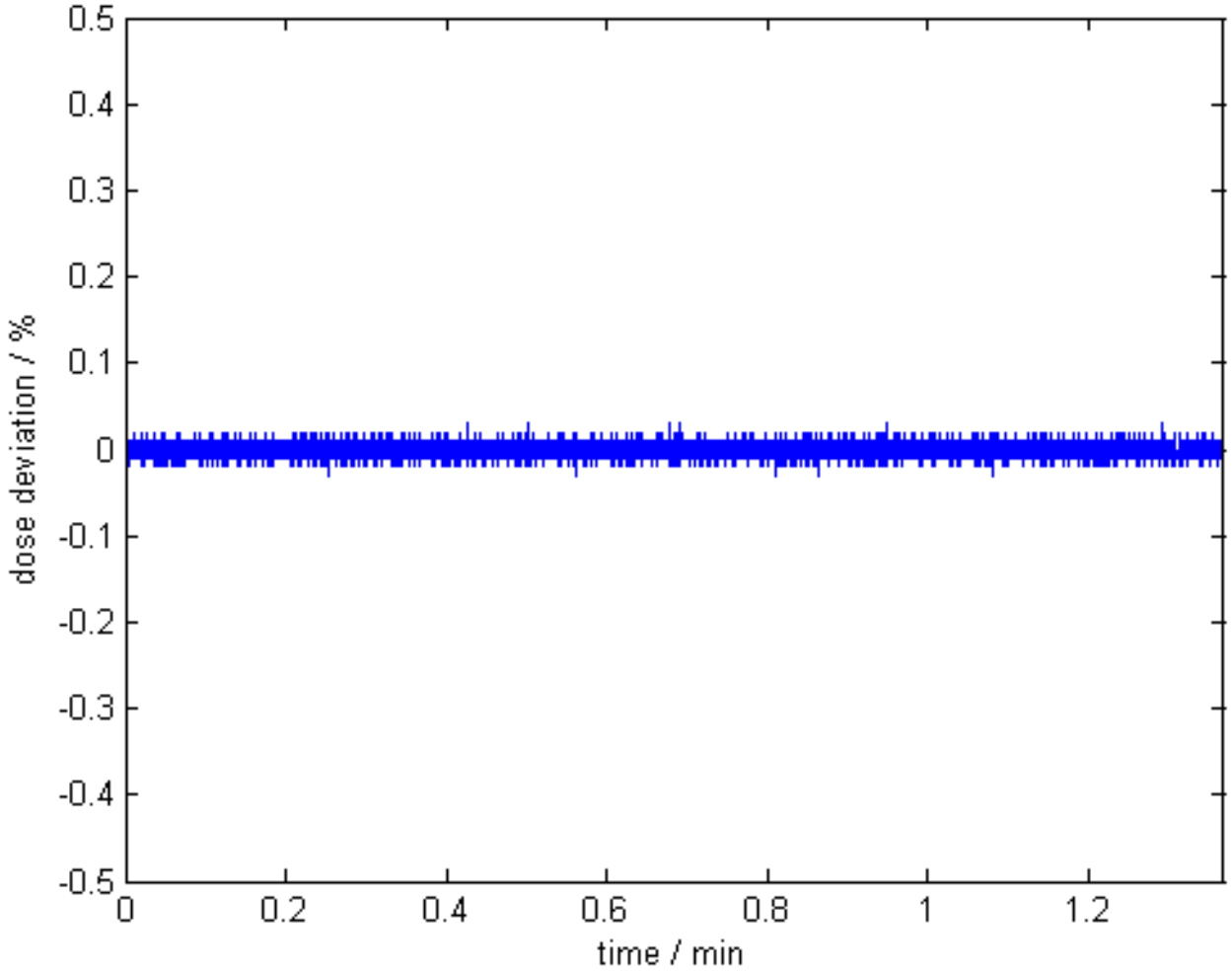
3 σ < 0.2%

- Small ΔDose → Small ΔCD
- Large ΔDose → Large ΔCD



LDP Dose Stability at 20kW

- Dose stability specification: 3 σ < 0.2%



LDP Technology For HVM

How To Ensure Tight Dose Stability ?

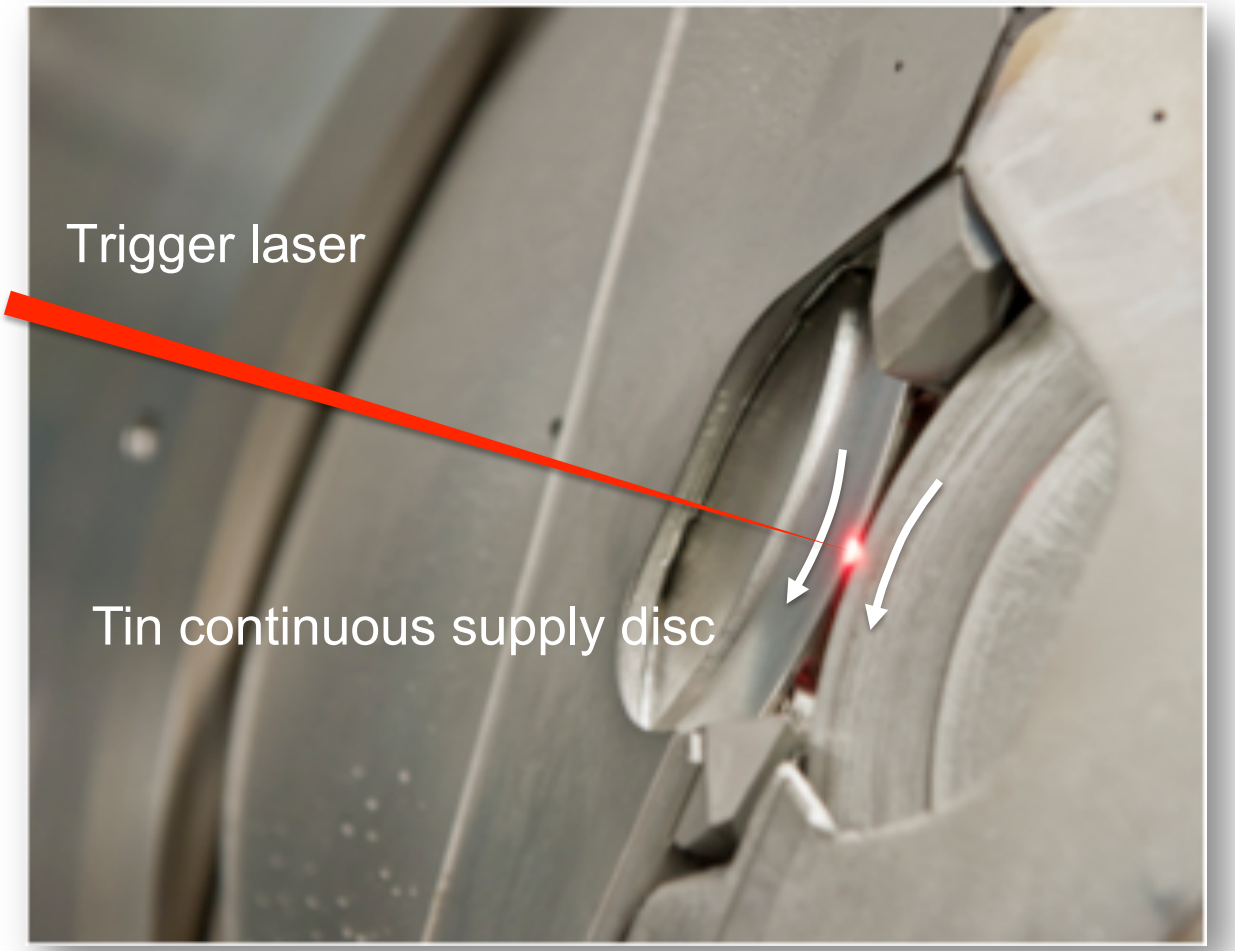
LDP Stability = Continuous Tin Delivery

- Tin delivery is continuous

→ No temporal discretization

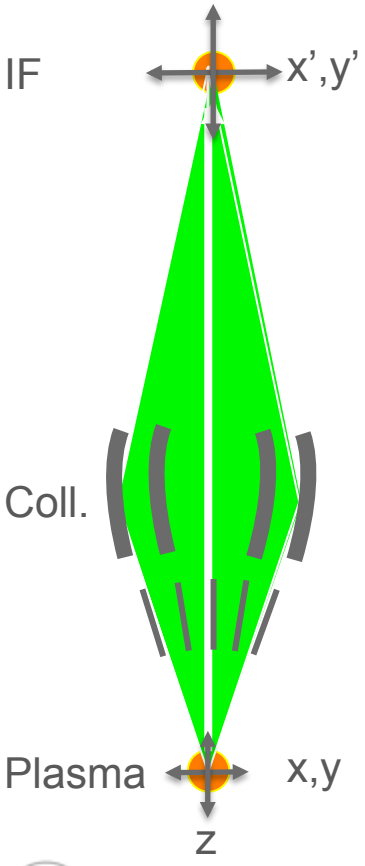
→ No missing target

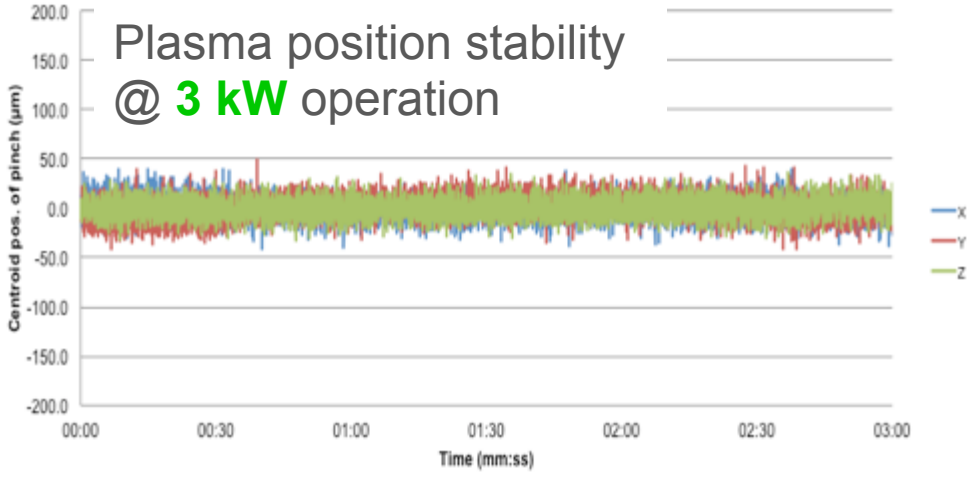
→ No missed pulse

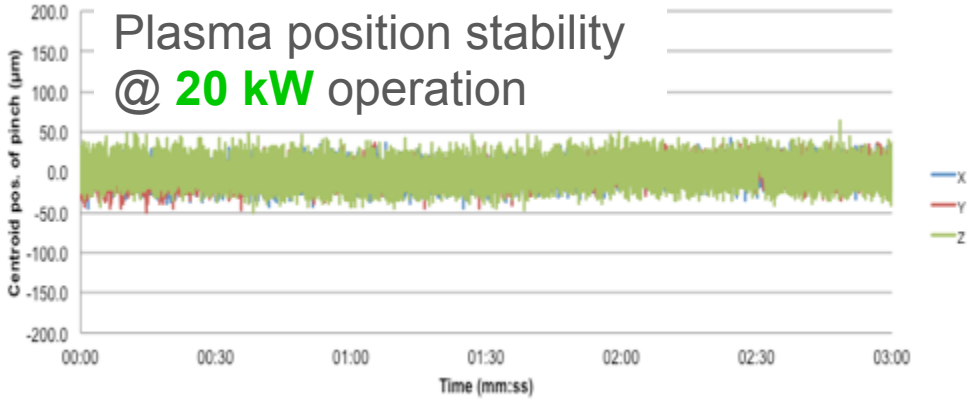


LDP Stability = Plasma Position Stability

- Laser focus, Tin and plasma are always at the surface of the wheel
  - Plasma position remains stable with power scaling







→ Stable laser focus

→ Stable plasma position

→ Stable Far Field image

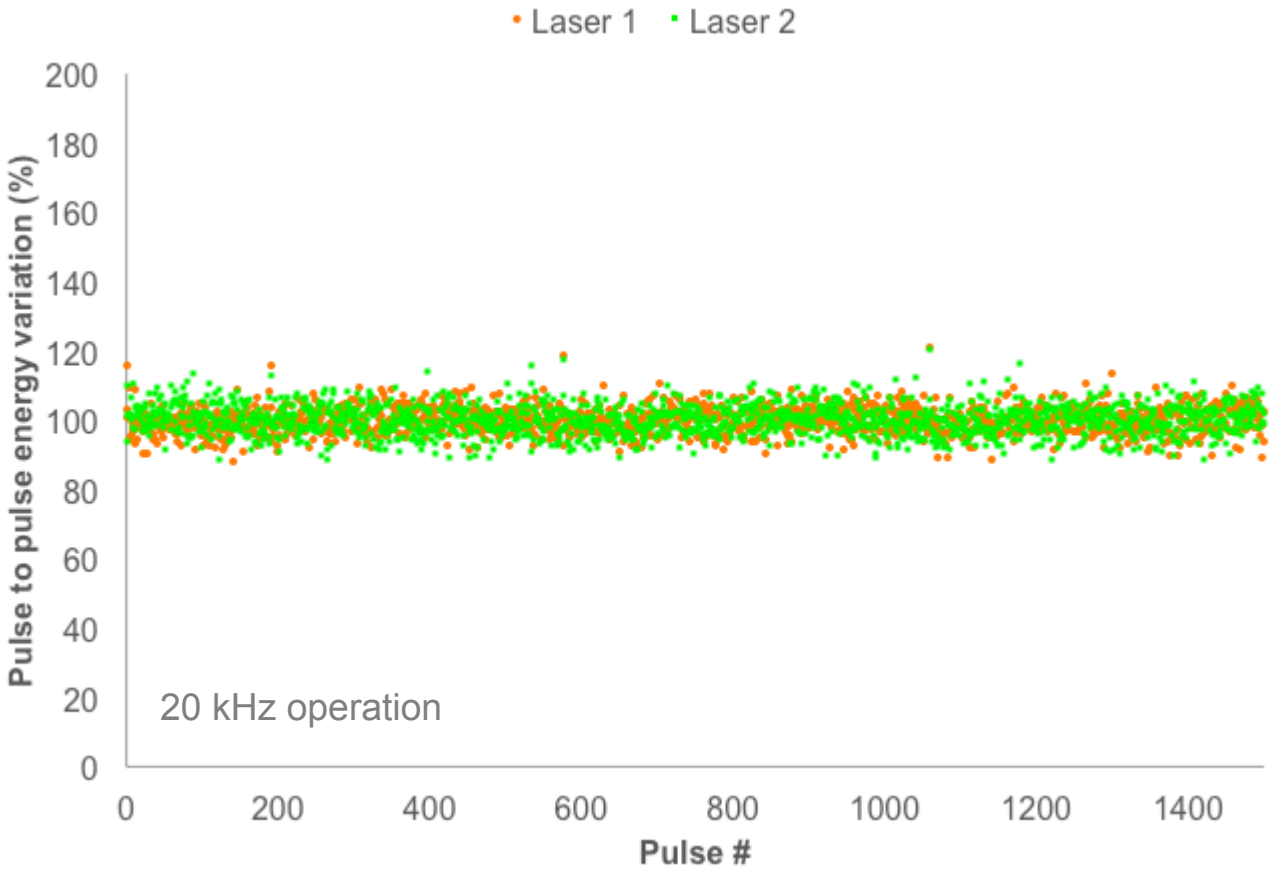
→ No dose variation caused by plasma position instability

LDP Stability = Trigger Laser Energy Stability

→ Trigger laser intensity stability

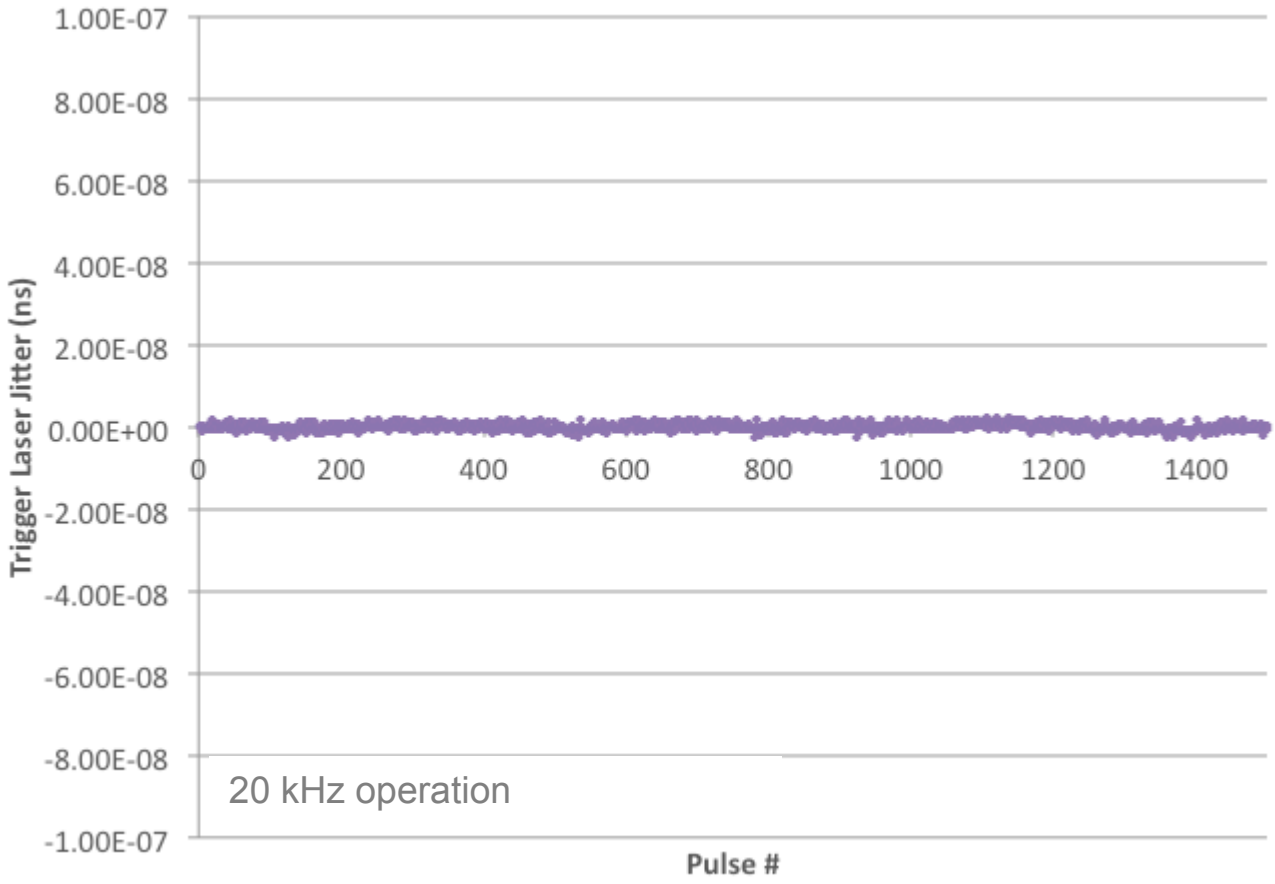
→ Tin vaporization repeatability

- Trigger laser stability makes Tin vaporization and plasma production highly reproducible



LDP Stability = Trigger Laser Timing Stability

- The jitter between trigger laser pulses is kept << 1 ns

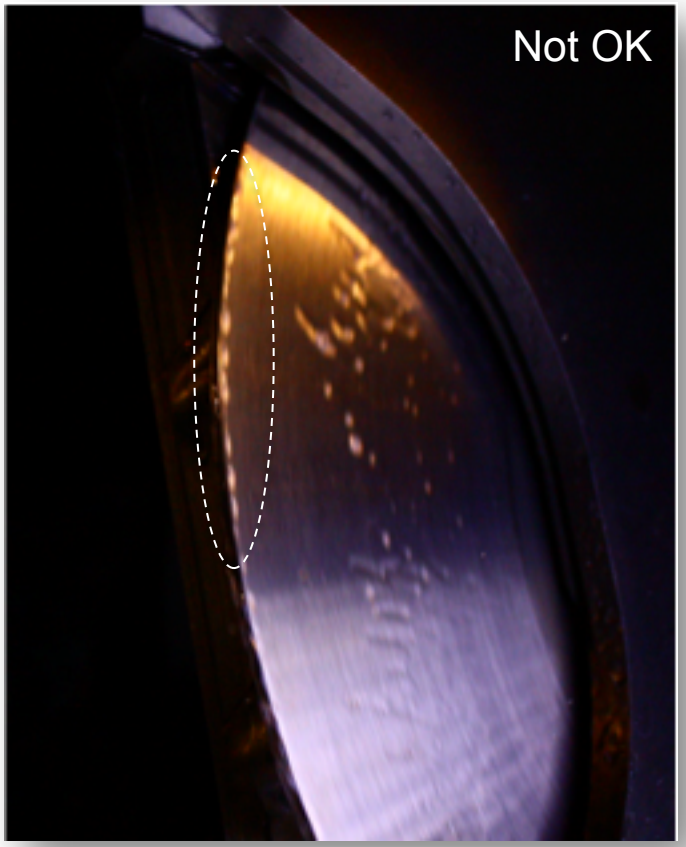


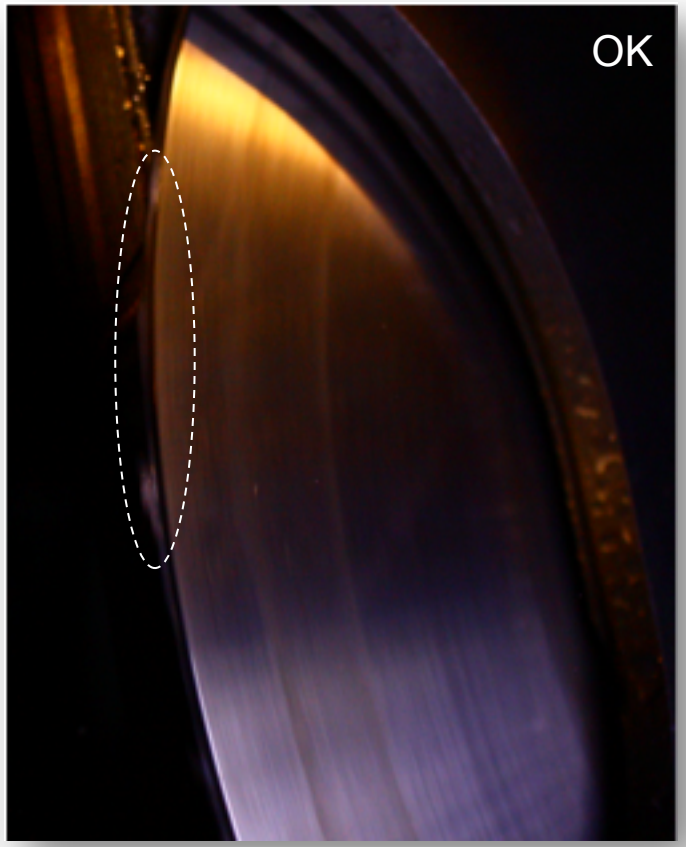
→ No timing instability

→ Tin vaporization is highly reproducible

LDP Stability = Tin Flow Uniformity

- The amount of Tin vaporized (with each trigger pulse) is highly repeatable





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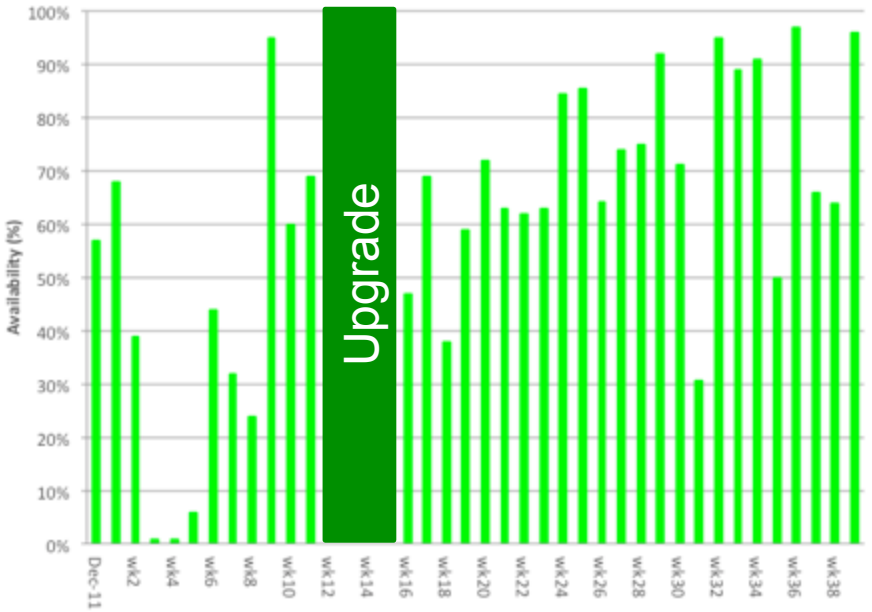
XTREME's 2012 Objectives

- To drastically improve and stabilize the reliability of XT's 3100 source at IMEC to enable Affiliate Chipmakers to develop their EUV process

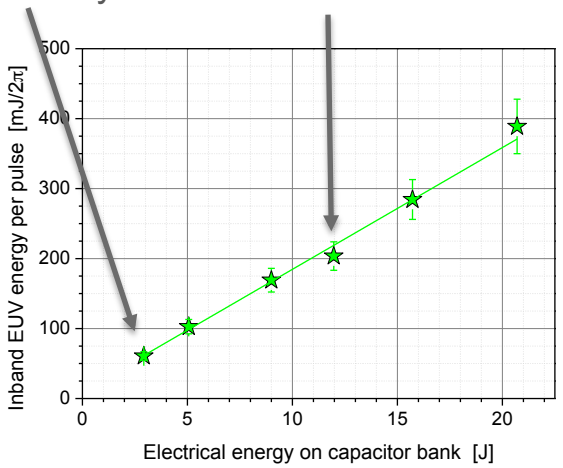
☑ Done

- To prove LDP long term scalability

☑ Done



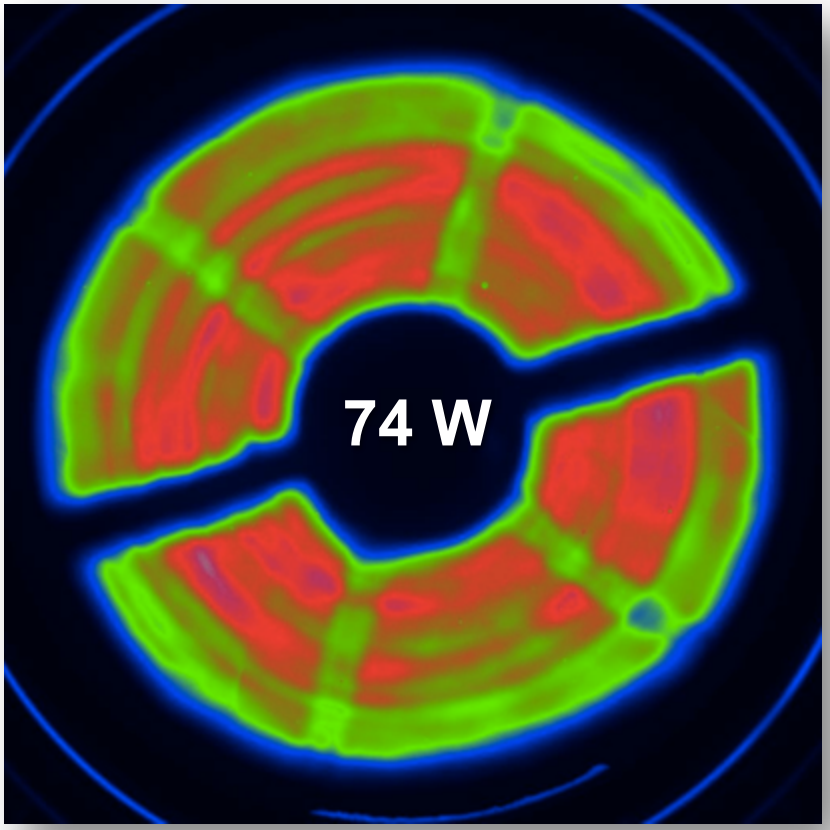
~ IMEC Today ~ NXE:3300 B >> NXE:3300 B



XTREME's 2012 Objectives

- To resume power scaling and demonstrate feasibility of 50W

☑ Done



- To upgrade XT's 3100 source at IMEC for higher power

☐ Soon

Conclusions

- EUV is a reality in the making supported by recent progresses of LDP
- No more claims. Results are in:
  - LDP is scalable in the long term
  - 74W power after IF was demonstrated on an integrated source
  - LDP technology is now being turned into a viable product and high uptime is achieved
- Next is to demonstrate 50 W @ 100% DC
- The night is always darker before dawn … but the EUV revolution is around the corner

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Acknowledgments

- XTREME would like to acknowledge this work has been possible thanks to a very valuable and fruitful collaboration with Fraunhofer ILT

- XTREME would also like to thank NEDO for their continued support

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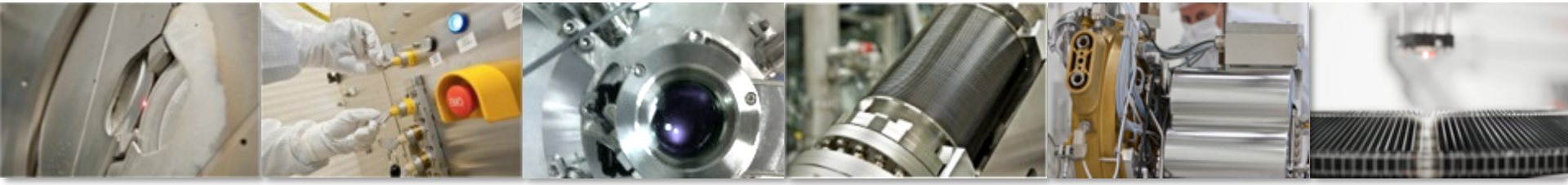
THANK YOU VERY MUCH FOR YOUR ATTENTION



XTREME technologies GmbH
www.xtremetec.de